Simple Sensor Network Utilizing Power Supply Wires for Data Transfer

VAŠEK V., DOLINAY J., DOSTÁLEK P.
Faculty of Applied Informatics
Tomas Bata University in Zlin
nám. T. G. Masaryka 5555, 760 01 Zlín
CZECH REPUBLIC
vasek@fai.utb.cz http://www.fai.utb.cz

Abstract: - This paper presents system for communication between sensors and central unit using power lines. The system is intended for wide range of applications in which it is needed to collect data from several sensors connected by two-wires only. The wires provide power to these sensors and at the same time transfer the data. The paper describes hardware and software implementation of the parts of the system – the receiver unit, the sensor transmitter unit and programming unit - and also the communication protocol which is used.

Key-Words: sensor, microcontroller, power line communication, data transfer, HCS08, PWM

1 Introduction
Process measurement is one of the most important tasks in the control system. It follows from the fact that control accuracy is fully dependent on how precisely the measuring chain works. These days there is number of devices available performing data acquisition tasks – standard cards for PCI or ISA bus which are suitable for standard personal computers and its industrial versions and modules for industrial automation usually equipped with RS485, CAN and other interfaces [4]. Independent category is formed by smart sensors incorporating sensor, converter to unified signal and data acquisition device in one embedded system with very compact dimensions and low power consumption. They have number of advantageous features, such as automatic diagnostic and calibration, high accuracy and immunity against electromagnetic interference due to short signal paths. Such sensors can be found in increasing number of applications, including automotive and aircraft industry where compact dimensions and low weight are crucial.

Quite often it is necessary to measure data in terrain where it is not possible to use standard computer equipped with DAQ card. In this case it is very advantageous to use laptop computer or other device with suitable communication interface equipped with portable sensor network.

The main idea is to develop simple sensor network minimizing number of hardware components of the sensor unit, its configuration complexity and deploy time of the measurement system.

2 Overview of the system
The system was designed with the following requirements in mind:
- Use only 2 wires which both provide the power and carry the data.
- Transfer data securely, detect and discard damaged data.
- Make the devices as cheap as possible.

The system consists of one or more sensors (transmitters) which are all connected to one two-wire line starting from a central unit (receiver). All sensors are powered from this line. Transmitting data from the sensor is done by lowering the voltage of the power line by switching on a load in the sensor. The receiver monitors the voltage and interprets the changes as logical zeroes and ones in the transmitted digital data.

Fig.1. Sensor network block diagram.
The communication is only possible in one way – from the sensor to the central unit. This could be considered a drawback, but for intended application of collecting data from e.g. temperature or humidity sensors, this one-way communication is sufficient. It has the advantage of simplicity both in software and hardware of the sensor. We considered also master-slave model with the central unit being the master which requests data from the sensors (slaves) only when needed. This would mean better use of the bandwidth – sensors would transmit data only when requested. But on the other hand if we decide to allow the sensors to also receive data, it would require extra circuitry in each sensor which increases the price and also it complicates the setup of such system – address of each sensor must be defined in the central unit with the polling interval etc. After considering all pros and cons we decided for one-way communication solution. In this solution each sensor transmits data with predefined period. This period can be fixed (e.g. 10 seconds) or it can be programmed into the sensor during initial setup, together with unique serial number. In the central unit it is easy to choose the period with which the data from sensor are received and drop the extra measurements, which are not needed.

2.1 Main components of the system
The system consists of three main parts: central unit (receiver), sensor unit (transmitter) and a programming unit.

2.1.1 Central unit
This unit receives data from all the sensors and provides these data to supervisory system. In our design this is a simple MCU-based device which handles the low-level operations and presents data to a personal computer for storing, displaying etc. Of course, it would be possible to create a unit which would also present the data on display or store them to storage device.

Basically the unit provides power source for all the sensors and it monitors the voltage of the power source to receive data from the sensors.

2.1.2 Sensor unit
The sensor unit is the transmitter, which transmits data to the central unit with given period. For example, this can be temperature sensor which sends current temperature every minute. In fact we can divide this unit to two parts – the sensor itself (e.g. integrated temperature sensor with PWM output) and the bus module, which handles the communication with the central unit. In our design the sensor unit is equipped with simple 8-bit microcontroller which handles both the communication on the bus and with the sensor itself. Three sensor types are supported – sensors with analog output, with PWM (or other digital) output and with serial output (SPI, IIC).

2.1.3 Programmer unit
The programmer unit is device which is used for initialization of the sensor units. It is assumed that the MCU will be already programmed when mounted onto the board and change of the firmware will not be possible. However, it is possible to store some configuration data into the MCU, such as unique serial number of the sensor, period of transmission and possibly other data. The programmer unit allows writing these data. It is a simple MCU-based device which is connected to the sensor unit to be programmed and to a PC which provides user interface, stores the database of IDs, etc.

2.2 Communication protocol
As mentioned above the sensor units transmit data to the central unit by the means of lowering the voltage of the power source, which is monitored in the central unit and decoded as logical ones and zeroes. It uses PWM encoding with period of 2 ms; the pulse is the voltage drop. Whether this drop is interpreted as one or zero depends on its length. Nominal length of 0.8 ms represents 1, length 0.35 ms represents 0. The software allows for inaccuracy in the length up to certain limits – these limits were experimentally set to +/- 0.1 ms. Voltage drops of a length which does not fall into the tolerance are considered a noise and ignored.

Data are sent in packets. Each packet begins with 3 ms start pulse, delay of 2 ms, then transmission of the data bits with 2 ms period. The structure of the data can be seen in Fig. 2.

![Data packet structure](image)

Fig.2. Data packet structure.
There is 1 byte for the ID of the sensor, one byte with length of the data, the data itself and then 1 byte CRC. The CRC is used detection of errors including collision (if more than one transmitter transmits at the same time).

3 Hardware of the system

Hardware of the system can be divided into the three types of units: sensors transmitting data to the bus, central unit receiving data from the bus and finally programmer unit which is used to program configuration data to the sensor using simple TTL UART interface.

Sensor and central unit hardware design is based on 8-bit microcontroller Freescale MC9S08SH8. It is a member of low-cost, general purpose, high-performance 8-bit flash-based microcontrollers with Von-Neumann architecture. Central processor unit with enhanced HCS08 core is fully upward compatible with Freescale HC05 family. CPU architecture is fully optimized for C language compilers. On the chip are integrated many of modules, for example [1]:

- On chip 8 KiB FLASH memory with in-circuit programming capability
- 512 B on-chip RAM
- Up-to 40 MHz CPU clock speed
- Two 2-channel 16-bit timer/pulse width modulator modules (TPM)
- Serial communication interface (SCI)
- Serial peripheral interface (SPI)
- 10-bit Analog-to-digital converter with 12-channel analog multiplexer
- 17 general-purpose I/O pins, 1 output only
- Watchdog system
- and other modules, see [1].

Sensor unit hardware can be divided to the three functional blocks:

- Power supply
- Modulator
- Control logic

Input voltage from the bus enters power supply circuit which is based on three terminal positive voltage regulator 78L05 with output voltage of 5 V and 100 mA output current capability. It is used for supply digital parts such as microcontroller and sensor connected to sensor unit I/O interface. Diode D1 connected before regulator protects sensor units from polarity reversal and separates filtered supply voltage from the bus too. Without this diode it would be impossible to effectively modulate bus voltage when data transfer takes place due to high-capacity filter capacitors in each sensor module. From the non-stabilized filtered bus voltage is supplied operational amplifier LM358 which is used in modulator and bus voltage sensing feedback circuit. All sensor unit functions are controlled by microcontroller Freescale MC9S08SH8 (IC1).

System clock is generated by Pierce crystal oscillator with output frequency of 32.768 kHz (Q1) connected to EXTAL and XTAL pins of the MCU. External reference clock is by internal MCU’s PLL circuit increased to 40 MHz resulting in internal bus clock frequency of 20 MHz. Modulator circuit consists of operational amplifier IC3A and MOSFET IRF630 (T1) acting as constant current

![Sensor unit (transmitter) schematics.](image)
load switched with PTC3 pin of MCU to on or off state leading to the bus voltage variations when data are transmitted. Before and during data transmit MCU is sensing bus voltage which is to appropriate level for A/D converter adapted using voltage divider R5, R6, R7 and operational amplifier IC3B. Bus voltage sensing is used for collision detection and monitoring of modulator function. Sensor is connected to the 14 pin sensor I/O interface SV2 providing two analog inputs complete SPI interface (signals MISO, MOSI, SPSCK), two general purpose digital inputs and outputs and regulated 5 V supply voltage. Sensor unit configuration can be updated by TTL UART interface connected to 3 pin pinheader SV3. BDM interface connector SV1 is used for device firmware updating respectively for debugging in SW development stage. Complete sensor unit schematic is depicted in Fig. 3.

Central unit utilizes same microcontroller type as sensor unit. Its hardware can be divided to six functional blocks:
- High-pass filter and over-voltage protection
- Low-pass filter
- Amplifier
- Control logic
- Communication interface
- Power supply

Bus voltage first enters high-pass filter with over-voltage protecting circuit eliminating DC component from useful signal. Then signal shape is corrected in the Butterworth type low-pass filter and after amplification is directly brought to the analog input of the MCU. Communication interface is in basic version standard RS232 realized by TTL to RS232 level converter MAX232 connected to MCU UART interface. There is an option to use USB interface utilizing USB UART interface FT232BM integrated circuit [3]. In this case computer detects central unit as standard USB serial port device.

## 4 Software of the system

The software consists of programs for the MCUs in the central unit, sensor unit and programmer (embedded software) and the programs for PC which allows communication with the central unit and the programmer unit (PC software).

### 4.1 Embedded software

The embedded software is written in C language, created in Freescale Code Warrior IDE. The program for the transmitter is rather simple, its main task is to generate PWM signal on output pin. Data to send are read from selected input of the MCU and transmitted. This repeats with defined time period. The program also handles UART communication, used for setting the ID, type and other parameters.

### 4.2 PC software

The PC software is still under development. Currently a terminal program is used on PC for communicating with the central unit and programmer. In future we plan to create standalone GUI applications which will allow more comfort in controlling the units.

## 5 Conclusion

This paper described system for collecting data from sensors using just two wires, both for powering the sensors and for communication. The system can be used in places where there is need to monitor several quantities in a number of places, such as, for example, monitoring the temperature and humidity in a building or in a technological process. The components are based on 8-bit microcontrollers and designed to be cost effective and simple to implement. The development of the system is still in progress and more features will be added in future.

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