Universal Sensor Interface

Xiujun Li, Gerard C.M.Meijer, Peter Avramov and Mathijs van der Lee*
Delft University of Technology, Faculty of Information Technology and Systems
Electronic Instrumentation Laboratory,
Mekelweg 4, 2628 CD Delft, The Netherlands,
*Enraf B.V. Delft, The Netherlands
E-mail: p.avramov@its.tudelft.nl ;
Phone: +31 15 2785026 ; Fax: +31 15 2785755

Abstract - **The paper reviews the ideas for development of a new low-cost Universal Sensor Interface (USI) as a complete analog front-end for low-frequency measurement applications. The USI provides an interfacing for many sensor elements as capacitors, platinum resistors, thermistors, resistive bridges, thermopiles, thermocouples and sensors for voltage and conductivity measurement. In addition of this main feature, the USI provides also temperature measurements for a compensation of temperature effects. The key part of the USI is a period-modulated oscillator, which converts the sensing element signals into time modulated output signal. The use of a three-signal measurement technique enables a continuous auto-calibration, high accuracy and reliability. The USI can be used as a stand-along device or a controlled device in different smart sensor systems and will be realized in a low-cost CMOS technology.**

Key words - **Smart Sensors, Sensor Interfaces, Smart Sensor Systems.**

1. INTRODUCTION

In the medium volume industrial and cost driven market, the investment in the development affects seriously the price of the final products. In [1], it is shown that the traditional top-down and bottom-up design approaches have several limitations when design the low-cost high performance sensor systems. To overcome this limitations, components, designs and tools should be reused as much as possible. Fig. 1 shows a possible hardware configuration for a smart sensor system in which powerful components, such as a microcontroller and a sensor interface have been used.

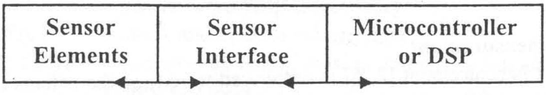

Fig. 1 Smart Sensor System

In such a system, the microcontroller's memory makes it feasible to collect information over a longer period for a number of sensors. This enables the realization of several important functions in the sensor interface, such as auto-calibration, self-testing, the compensation and filtering of undesired signals and effects. Employing the advanced measurement techniques and a low-cost CMOS technology, a high-performance, low-cost Universal Sensor Interface (USI) can be produced.

2. MEASUREMENT TECHNIQUES

2.1 The three-signal technique

In order to realize the mentioned functions, several measurement techniques have been used in the USI. The three signal technique is used to eliminate the effects of unknown offset and gain in the linear systems [5]. The final measuring result in three phases mode is given by the ratio M:

$$M=(T_x - T_{off}) / (T_{ref} - T_{off}).$$

In this ratio, the influence of the unknown offset and gain of the measurement system is eliminated. Fig. 2 shows the USI's output signal in three phases mode. During the first phase T_{off}, the offset of the complete system is measured. During the second phase T_{ref}, the reference signal form the reference element is measured and during the last phase T_x, the signal itself is measured.

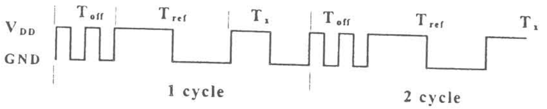

Fig. 2 The output signal of the USI for a 3-phase mode.

2.2 An advanced chopping technique

An advanced chopping technique [2] is used to reduce the effect of offset, 1/f noise and low-frequency interference. This enables the use of low-cost CMOS technology for accurate measurement systems.

2.3 Two-port measurement

The two-port measurement [2, 6] is employed to reduce the effects of shunt and series impedances of the wires and cables used to connect the sensor elements to the interface circuit.

2.4 Dynamic element matching technique

Dynamic element matching technique [2] is used to obtain an accurate on-chip division or amplification factor without the use of additional trimming.

2.5 Dithering technique

Dithering technique will reduce the effects of high-frequency interfering signals, which are introduced by the microcontroller or the other digital circuitry in a sensor system.

3. STRUCTURE OF THE USI

3.1 Architecture of the USI

The USI is a complete analog front-end for low frequency measurement applications. The main part of the USI is a period-modulated oscillator. Its function is to convert the voltage signals of the sensing elements into the period-modulated signal, which is microcontroller or DSP-compatible.

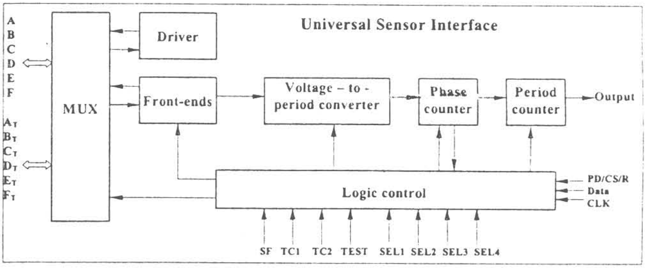

Fig. 3 Architecture of the USI

Fig. 3 shows the architecture of the USI and its terminals for:

- A - F - primary sensors
- A_T-F_T - temperature-compensation sensors
- PD/CS/R - power down/chip select/reset
- CLK, DATA - clock and control pattern data
- TC1, TC2, TEST - temperature compensation and USI's linearity test
- SF - slow/fast mode
- SEL1 - SEL4 - mode selection

Working as a stand-along device, the USI can be controlled via the terminals, PD/CS/Reset, SF, TC, TEST, SEL1 - SEL4. When the USI works as a device controlled via a SPI bus, the terminals, PD/CS/Reset, DATA and CLOK are used to control the USI. For temperature compensation, two program pins (TC1, TC2) and also six input sensing pins (A_T – F_T) can be provided. When there is no temperature compensation, probably a high speed is desired. Therefore, we can use second pin, TC2, to select a very high speed mode in addition to the slow and fast modes of the USI.

3.2 Signal Processing

The signal processing in the USI is as follows: The input sensor signal is selected by the multiplexer (MUX). Next, this sensor signal is converted into a chopped voltage signal by the corresponding front-end circuit. Finally, the voltage signal is converted into a period length. The phase counter and period counter perform the phase control and period multiplication (frequency division), respectively. The logic circuit controls the mode of the USI. The output signal of the USI chip is a period-modulated square-wave signal. The three-state output feature enables the parallel output connection to a single output wire. Only one of these USI's outputs is activated via its PD control pin. This enables to connect more than one chip to an addressable sensor bus.

4. PROTOTYPE SETUP OF THE USI

The prototype setup of the USI has been developed, using the known Universal Transducer Interface (UTI) [3].

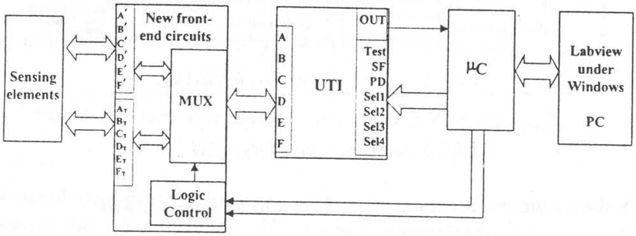

Fig. 4 An overview of the prototype setup.

Fig. 4 shows an overview of the setup, which mainly consists four parts: new front-end circuits, the UTI, a microcontroller and PC. The new front-end circuit enables the connection of a number of sensing elements. The microcontroller controls the modes of the circuit, reads the output signal, processes the data and provides the communication with the PC. Using the Labview program, the PC is used as a virtual instrument which displays the results in real-time. The new front-end circuit can be implemented by using a special multiplexer and a logic control circuit, which sets the mode. The pins A-F correspond with ones of the UTI. The pins A′-F′ offer connections of the sensing and reference elements for the primary functions of the setup, while A_T- F_T are connected to the sensors for temperature compensation. This prototype setup shows:

- the typical specifications and functions of the USI
- how parts of the UTI can be reused in the USI
- the data processing
- the requirements for new frond-end circuits
- the sensitivity for external interference

4. MODES, RANGES AND FEATURES OF THE USI

The USI can work under one of the following modes for many types applications:

Modes	Sensing elements/Values/Applications	Name
1	Grounded Voltage, 0 - 1 V (pH)	GV1000
2	Grounded Voltage, 0 - 200 mV (thermocouple)	GV200
3	Floating Voltage, ±200 mV (thermocouple)	FV±200
4	Floating Voltage, ±25 mV (thermopile, thermocouple)	FV±25
5	Floating Voltage, ±2 mV (thermocouple)	FV±2
6	Conductivity, 0- 100μS/cm	Conduct
7	Capacitance, 0 pF to 300 pF (humidity)	C300
8	Pt 100/1000 2/ 3/ 4-wire connection with long cable wire	Pt100/1000
9	Thermistor 1-25 kΩ, 2/3/4 wire connection (long cable)	Therm
10	R Bridge -Voltage reference, output range ±200 mV	RBV±200
11	R Bridge -Voltage reference, output range ± 25 mV	RBV±25
12	R Bridge -Current reference, output range ±200 mV	RBC± 200
13	R Bridge -Current reference, output range ± 25mV	RBC±25
14	Platinum resistor with external MUltipleXer	PtMUX
15	ThermoCouple with external Multiplexer, ±200 mV	TCM±200
16	ThermoCouple with external Multiplexer, ±25 mV	TCM±25

Providing an interface for many types of sensor elements, the USI has the following main features:

- Measurement of multiple sensor elements
- Continuous auto-calibration of offset and gain
- Tri-state, microcontroller and DSP-compatible output signal
- 2/3/4-wire measurement available for almost all measurements
- AC excitation voltage signal for all sensor elements
- Suppression of 50/60 Hz interference
- Temperature compensation
- Work as a stand-along device or under SPI control

5. CONCLUSIONS

In the paper, the USI for a large spectrum of sensor elements is proposed, as a complete analog front-end for low frequency measurement applications. Based on a period-modulated oscillator, the USI employs many advanced techniques. This enables to reach a higher accuracy and reliability. The measurement results from the prototype setup, show that it is possible to develop a high-performance, low-cost universal sensor interface. The implementation in a low-cost CMOS technology will make the USI competitive in the medium volume and cost driven market.

REFERENCES

[1] F.N.Toth, "A design methodology for low-cost, high performance capacitive sensors", PhD. thesis., Delft University of Technology, 1997.
[2] F. van der Goes and G.C.M. Meijer, "A universal transducer interface for capacitive and resistive sensor elements," Analog Integrated circuits and Signal, Processing, Vol. 14, No. 3, Nov. 1997, pp. 249-260.
[3] Smartec, "Universal Transducer Interface (UTI), Revolution in Sensor Interfacing," Users Guide 1997, Breda, The Netherlands
[4] X. Li and G.C.M. Meijer, "Preliminary specifications of universal sensor interface (USI)," June 1999.
[5] F. van der Goes, "Low-cost smart sensor interfacing," PhD. Thesis, Delft University of Technology, April 1996.
[6] G. G. M. Meijer, "Concepts and focus point for intelligent sensor systems", Sensors & Actuators, Vol. 41, No. 1-3, pp. 183-191,1994.