SENSORS FOR SMART TEXTILES

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REZUMAT. Studiul abordează textile inteligente care conţin dispozitive electronice încorporate. S-a efectuat un studiu experimental pentru un sistem de măsurare şi afişare a temperaturii cu un traductor comercial TMP 100. După proiectarea schemei electrice pentru sistem, s-a elaborat şi implementat codul pentru afişarea temperaturii măsurate cu senzorul digital. Apoi, s-a realizat sistemul funcţional şi s-a efectuat un studiu de eroare. S-a constatat că sistemul creat poate fi utilizat la măsurarea şi afişarea temperaturii în interior şi în mediul exterior, pe materiale textile sau în diferite incinte, pentru monitorizarea şi reglarea temperaturii, atunci când este cazul.

Cuvinte chele: textile inteligente, senzori.

ABSTRACT. The study is about smart textiles containing integrated electrical devices It has been made an experimental research for a measurement and display of temperatures the using a commercial sensor model TMP 100. After, the electrical schema for the system was designed, the software for displaying the measured temperature with the digital sensor was elaborated and implemented. The next step was to make the functional system and to determine the performances. This system could be used for measuring and displaying the temperature inside and outside, on fabrics or in different chambers, for monitoring and controlling the temperature when needed.

Keywords: smart textiles, sensors.

1. INTRODUCTION

The concept of smart textiles (or smart fabrics) have been introduced a few decades ago and it was widely used in the 90s to define the dynamic behavior of materials which are continuously changing their properties under external factors.

Smart and interacţive textiles compose an emerging interdisciplinary field, which connects experts of information technology, electronics, material science, textiles, and so on. The purpose of this new field is to develop technologies and manufacturing techniques for economic output of versatile, flexible computer systems, and secondly, large-area textiles based on computer systems with unique applications for different end uses. Smart and interacţive textiles will be highly applied in the next generation of fibers, fabrics and textile products [1].

Many smart textiles are already on the global market in all sorts of opportunities and applications including casual clothing, medical textiles, in military, protective and safety clothing, automobile textiles as well as in the space exploration. Integrating and combining of advanced instruments with advanced smart fabrics creates a bright future of the textile market dynamics worldwide.

As it can be seen in the text above, the topic of smart textiles is highly complex. The aim of this study is to approach electronic fabrics, especially the fabrics with incorporated electronic devices (sensors or transducers). Among the many possible parts of smart fabrics, sensors were chosen because without them is impossible to retrieve information of any system. Therefore, a bibliography survey was made which intended to define several fundamentals and transducers characterization.

Further, an experimental research was initiated for temperature measurement system with a TMP100 type commercial system. The genuine contributions regarding this system are:

− wiring diagram design for the system;

− key (code) writing and implementation for the measured temperature display with digital sensor;

− functional system achievement;

− an experimental study of its errors.

The entire study leads to several conclusions that point out the improvement of transducers performances or electronic systems. These are integrated on textiles or other kind of materials and will remain a very important issue available for further development.

2. THEORY

Smart textiles is the new generation of fibers that can be described according to the common definition

as intelligent, so that are able to adapt their properties under the external conditions. Their properties include:

− color changing

− generates and transfers heat using electricity or phase changing.

− sensor properties, sensitive to environmental temperature changes

− have the capacity to save the shapes used before and return to them, generally under thermal conditions.

Considering their functions, smart textiles are clasified in four categories [2]:

1) *Passive smart materials* are materials or systems sensitive to environmental conditions or stimulus. These are sensors that show what have been changed upon them (color and shape, thermal and electrical resistivity). This class of materials are more or less comparably with operational and high performance textiles. Microfibres are extremely inactive, waterproof and in the same time permeable to water vapor.

2) *Active smart materials* are materials or systems able to feel and respond to external conditions and stimulus [4]. Their predefined functions consist of sensing and generating the response to stimulus, meaning that sensors and control elements work under environmental conditions.

3) *Very smart materials* are materials or systems that can perform triple functions. These are sensors able to retrieve environmental stimulus (1), respond to them (2), adapt and reshape under environmental conditions (3).

4) *Materials with even higher level of intelligence* develop artificial computer intelligence. This class of materials and systems are carried out by connecting very smart materials and structures with advanced computer interfaces.

A wearable smart textile system(Figure 1) includes:

− sensors;
− actuators;
− data processing unit;
− communication system;
− energy supply;
− interconnections.

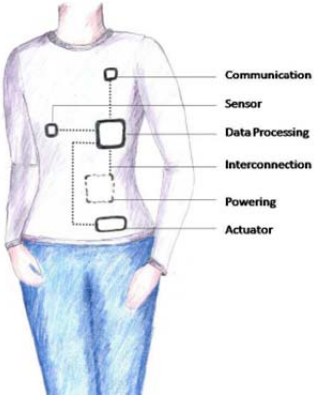

Fig. 1. Wearable smart textile system components [3].

Transducers are devices that converte a certain physical qantity in a different one, compatible with the automatic device which includes it. The provided informations are useful to the procesess automatic administration.

All transducers include a primarly transmitter also known as sensitive element or sensor. The sensor straightly retrieve from the process, the information about the followed parameter.

Electronic transducers convert the measured physical quantity in electrical quantity, by using electronic techniques. They are classified by several criteria:

− Nature of the input electro less physical quantity, which highlights the signal transducers: radiant, thermal, chemical, mechanical, magnetic, etc.

− The way in which the input signal is converted and the type of interconnection that brings together the transducers in: *direct* transducers (make one single conversion) and *complex* transducers (incorporates different types of direct transducers and sometimes auxiliary elements).

Direct conversion occurs in one single physical element while complex (indirect) conversion is made only when there are required several subsequent transformations of the input physical quantity.

− The operating principle, which classifies the transducers in: parametric (modulating) and energetic (generating) transducers.

Parametric or modulating transducers (sensors) convert the variaţion of input electro less quantity to the variaţion of electrical parameter (resistance, mutual inductance, capacity) and also they require auxiliary power supply (thermo resistance, strain gauges, photo strength, piezo resistance, bolometer instrument etc.).

Energetic or generating transducers convert the input electro less quantity to electric voltage, power or charge without needing any power supply.

In terms of shape of the output electrical signal, transducers are divided in analog transducers in which case the transmitted signal depends continuously on the input quantity, and numerical transducers case in which the output signal ranges discontinuously according to a particular key (encoding operation).

− Depending on the electro less quantity transducers are divided in:

- geometrical quantities: resistive, inductive, capacitive and numerical, of displacement, with radiaţion, of proximity;
- kinematic quantities: of velocity, of acceleration, of shocks and vibrations, gyroscopic;
- mechanic quantities: flexible (tensile, compressive, bending, torque); resistive strain gauge, with rousing string, magnetostrictive, of strength, of torque;
- technological quantities: pressure, flow rate, elevation;
- other types: embedded, etc.

The transducer performances are established based on the following characteristics:

- *transducers sensitivity* defined as the slope of static characteristic of the transducer. More generally, it is the minimum value of the input quantity (measured parameter) that will create the visible value of the output quantity;
- *sensitivity error*, is the deviation of real static characteristic from its ideal shape;
- *operating range* of a sensor given by the measurable minimum and maximum values of the parameter;
- *dynamic range* is the total measuring period of the sensor starting from the minimum to the maximum value;
- *fidelity* denotes the degree of reproducibility of a measurement;
- *resolution*, refers to the smallest incremental change detected of the input quantity which causes a detectable modification of the output quantity;
- *transducers deviation*, given by the output value when it should be zero (i.e. the difference between the real output value and the specified value in a few well known conditions);
- *transducers linearity* is an expression of distance defined by the remoteness of the actual curve (calibration curve) from the ideal curve;
- *hysteresis* is the sensor potential to follow accurately the parameter variaţion, regardless of (ascending or descending)the direction where its modification happen;
- *sensor's time of response* is the transitory process duration as it is generally defined for a system. Time of response is related to the parameter for time. This information is most of the time written on transducer's technical label;
- *sensor's dynamic linearity* defines its capacity to follow quick variaţions of the input value.

3. TMP100 DIGITAL TEMPERATURE SENSOR WITH I2C INTERFACE

TMP100 is an ideal sensor for large measurements, extended by temperature, in several areas of applications such as: communications, computers, consumers, environment, industry and different instrumentation applications.

TMP100 temperature sensor (Fig. 2) is compatible with I2C interface. It allows connection up to eight identical devices on the same database.

TMP100 is useful in temperature measurements operations in the –55 - +125 ^{0}C range.

The sensor does not need any external components there for it displays a resolution of 9 bytes, set in the sensor's configuration register through the microcontroller with an accuracy of ±2 ^{o}C in the –25 - +85 ^{o}C temperature range and ±3 ^{o}C for –55 - +125 ^{o}C temperature range.

For interfacing there is used I2C interface, making sure that the pull-up resistors R_1 and R_2 are connected between the data lines and the power supply of 5 V.

I2C connection need two pull-up type resistors (R_1 and R_2) designed to maintain the route in „1" logic. The two resistors have values in the 2 – 10 K range.

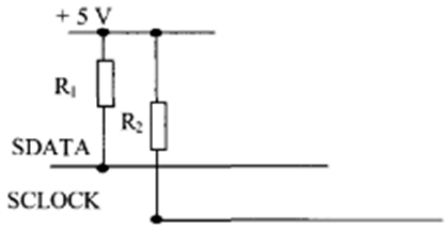

Fig. 2. TMP100-wiring diagram [7].

Condenser C = 0,1 j is used for decompression.

Table 1 presents the dependency between resolution and conversion time.

Table 1

Resolution and conversion time for TMP100 [7]

R_1	R_2	Resolution	Conversion time [ms]
0	0	9 bytes (0,5 ^{o}C)	40
0	1	10 bytes (0,25 ^{o}C)	80
1	0	11 bytes (0,125 ^{o}C)	160
1	1	12 bytes (0,0625 ^{o}C)	320

The inner structure of the temperature sensor is shown in Figure 3.

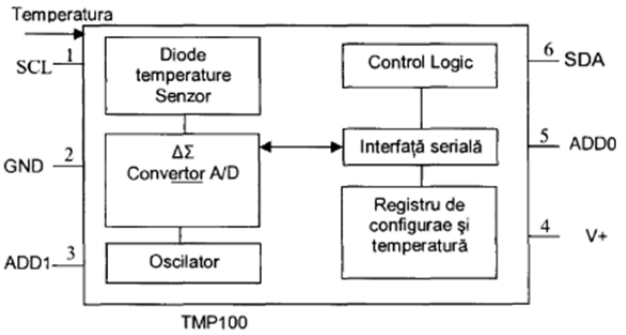

Fig.3. TMP100 sensor's internal structure [7].

Figure 4. presents the internal registers of the temperature sensor.

For the sensor's proper operation the following registers must be set:

- *temperature register* – used for the storage of the latest conversions;
- *configuration register* – used to set the sensor's operating mode and the resolution;
- *pointer register* – used to set intern registers with the microcontroller.

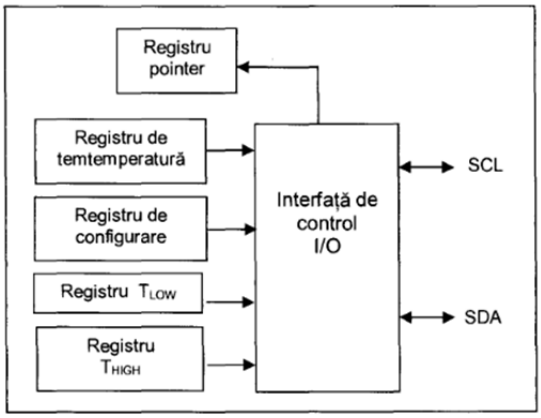

Fig. 4. Internal registers for TMP100 [7].

According to the TMP100 temperature sensor's technical documentation [7], the data bytes can have several values measured in Celsius degrees (Table 2).

Table 2

Data formats for temperature in Celsius degrees [7]

Temperatura [^{0}C]	*Iesire digitala (binar)*	*Codul hexa*
128	0111 1111 1111	7FF
27,9375	0111 1111 1111	7FF
100	0110 0100 0000	640
80	0101 0000 0000	500
75	0100 1011 0000	480
50	0011 0010 0000	320
25	0001 1001 0000	190
0,25	0000 0000 0100	004
0,0	0000 0000 0000	000
-0,25	1111 1111 1100	FFC
-25	1110 0111 0000	E70
-55	1100 1001 0000	C90
-128	1000 0000 0000	800

4. EXPERIMENTAL SECTION

Within the frame of the experimental research, there was carried out a I2C connection between a microcontroller of 8 bytes type PIC 16F690 and a digital temperature sensor type TMP100.

The analogical sensor takes over the temperature from the environment and transforms it in a data sequence of 9 bytes, using a A/D convertor.

For the sensor setup, first is necessary to set the 8 bytes registers; the address book (0) will keep the already read temperature and the configuration register (1) will maintain the configuration settings.

Figure 5. exhibits an original C code sequence, used for the sensor setup.

Figure 6. shows the overall wiring diagram of the experimental apparatus which composes:

- a LCD display, shows the temperature measured by the sensor;
- microcontroller type PlC 16F690;
- voltage controller type 7805T with the purpose to drive out a near 5 V voltage needed by the controller and LCD;
- TMP100 digital temperature sensor with an I2C interface.

```
#include<htc.h>
#include        "i2c.h"
void i2c_Stop(void) {
        SDA_LOW();
        SCL_HOGH();
        _delay_us(I2C_TM_DATA_SU);
        SCL_DIR=I2C_INPUT;
        _delay_us(I2C_TM_STOP_SU);
        SDA_HIGH();
        _delay_us(12C_TM_BUS_FREE);
        SDA_DIR = I2C INPUT;
        return;
}
void i2c_Start(void) {
        SDA DIR = 12C_INPUT;
        _delay_us(I2C_TM_DATA_SU);
        SCL_DIR = I2C_INPUT;
        _delay_us(I2C_TM_SCL_HIGH);
        SDA_LOW();
        _delay_us(I2C_TM_START_HD);
        return
}
```

Fig. 5. C code sequence.

D_1 diode is a rectifying diode of 1N4007 type. It is designed to stop the flow return through the UA7805voltage stabilizer, when the circuit is powered from a voltage source, when the connection to battery is not stopped (the stopped mechanical part of the connector's ground circuit is broken). Also, this diode serves to protect the circuit in case of reverse polarity (using the battery).

The UA7805 type voltage rectifier is designed to provide a 5 V voltage of the circuit. The C electrolytic capacitor is used to filter the power supply and the C ceramic capacitor serves to decompression.

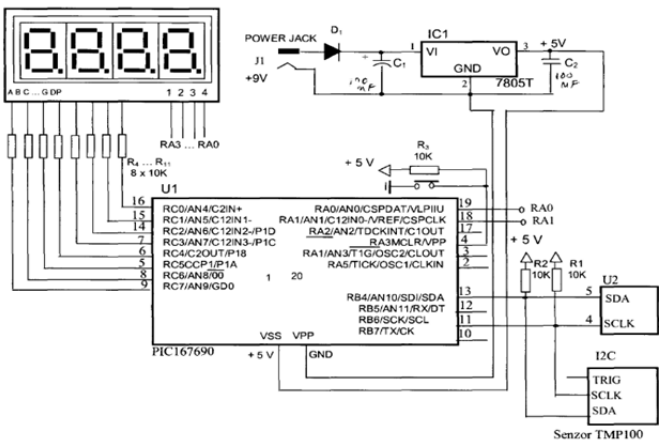

Fig. 6. The overall wiring diagram of the experimental set-up.

R_1 and R_2 resistors are pull-up types for the I2 C communications lines. These can have between 1 KΩ and 50 KΩ but, for the sake of stability at high frequencies small values are used (there resistor's

values are influencing the switching slope). Here there has been chosen resistors with values higher than 10KΩ.

5. RESULTS AND DISCUSSIONS

The motherboard is shown in Figure 8.

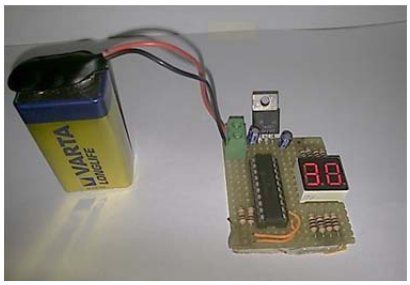

Fig. 8. System for temperature measuring and displaying.

With this system were carried out several experiments for the study of its errors.

The experimental results are presented in Table 3 and Figure 8.

Table 3

Accuracy (temperature error)

Test conditions	Accuracy (temperature error)
-25^0C to +85 ^{o}C	±0.5 ^{0}C
-55^0C to + 125 ^{o}C	±1 ^{0}C

Figure 8 and the Table 3 show that the studied system achieves the performances described in the scientific literature [7].

6. CONCLUSIONS

Electronic textiles have great prospects for development by: improving textile technologies and/or optimizing applied electronic devices.

The circuit for temperature display, designed and conducted in the present work, can be used in measuring and displaying the temperature both inside and outside, on fabrics and as well in different chambers for constant monitoring of the temperature. Also when it is necessary is possible to adjust the temperature to the default value.

For using fabrics the system needs and can be further miniaturized. In case of long term use of conductive textiles, for example, it is important to solve the stability issue.

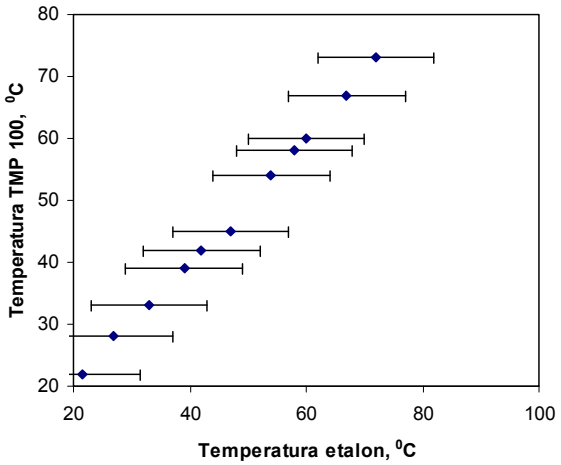

Fig. 8. Temperature accuracy.

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