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Device for Remote Temperature Measurement and Recording

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A device for remote measurement and recording of temperature is presented. A temperature logger is a device which measures an average value of temperature during an asserted time interval and records an average value of temperature into the device memory together with the time of measurement. The device has an RS232 serial port by which recorded data are sent to a computer and by which remote temperature measurement is possible. The application for the communication between a computer and a temperature logger is written in C# programming language

Key words: **measurement of temperature, remote measurement, logger.**

Introduction

PEOPLE have always had a need to measure temperature. With the development of computer systems, temperature measurement done on remote locations has become possible and measurement results can be displayed on central computers. Nowadays, remote measurement of temperature is performed in most industrial plants. In the T35 [1] and T38 [2], wind tunnels, continual measurement of temperature is necessary.

The wind tunnel data acquisition system measures voltage from sensors and sends measured values to the central computer. The data acquisition system has referent voltage sources which are influenced by precise temperature. The voltage of referent sources has a precise value within a certain temperature interval. It is therefore necessary to continually measure temperature in the place where data acquisition is performed. A temperature logger is developed in the Military Technical Institute with the aim of continual measurement of temperature during the work of a data acquisition system and wind tunnel testing (Fig.1). The temperature and dew point [3] are very important parameters in the wind tunnel testing.

Figure 1. Temperature logger

Sensors of temperature

There are several types of temperature sensors:

- resistance temperature detectors (RTD)
- thermocouples
- thermistors

Resistance temperature detectors are metal resistance thermometers made of platinum, nickel or copper. RTDs are sensors of temperature with the highest precision [4]. The best RTDs are made of platinum since platinum has linear dependence resistance to temperature in a wide range of temperature values [-200°C, 600°C]. Nickel and copper are also linearly dependent on temperature but in a narrow range. RTDs made of platinum are called platinum resistance thermometers (PTR). Platinum resistance thermometers can achieve a precision of 0.1°C. The most used platinum RTDs are Pt100 and Pt1000. The Pt100 got the name because it has a resistance of 100 Ω at a temperature of 0°C. The Pt1000 got the name because it has a resistance of 1000 Ω at a temperature of 0°C.

The advantage of thermocouples over other temperature sensors is an extremely wide measuring range of temperature [-267°C, 2316°C]. The disadvantage of thermocouples is that they measure relative temperature [5]. RTDs and thermistors measure absolute temperature.

Thermistors are resistance thermometers made of semiconductors. There are two types of thermistors:

- PTC thermistors
- NTC thermistors

PTC thermistors have a positive temperature coefficient which means that the PTC resistance increases with the increase in temperature. NTC thermistors have a negative temperature coefficient which means that the NTC thermistor resistance decreases with the temperature increase. Thermistors have high sensitivity of resistance to temperature changes. NTC thermistors have 10 times higher sensitivity than platinum resistance thermometers. PTC thermistors have 10 times higher sensitivity than NTC thermistors and 100 times higher sensitivity than platinum resistance thermometers. The disadvantage of thermistors is nonlinearity

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and a smaller measuring range than that of RTDs. The measuring range of thermistors is [-100°C, 500°C]. The nonlinearity of NTC thermistors can be greatly matched by putting an NTC thermistor in the Wheatstone bridge and by carefully choosing the resistance of the other three resistors in the bridge. Thermistors are very useful for measurements in smaller temperature ranges because of their high sensitivity. They are used for measurements in medicine, biology, meteorology, air-conditioning, etc. Today a great number of integrated circuits, which present temperature measurement sensors, have an integrated NTC thermistor settled in the Wheatstone bridge. These integrated circuits have A/D converters for the digitalization of the output voltage from the resistor bridge. Some of these integrated circuits are: LM75 [6], DS1621 and DS18S20. The temperature logger presented in this paper uses the LM75 integrated circuit for the measurement of temperature. The LM75 integrated circuit has the Wheatstone bridge with an NTC thermistor, a 9-bits sigma delta A/D converter and control logic for the I2C interface.

Power supply

Power supply is a very important part of the electronics for a temperature logger. Power supply must be realized in such a way that dissipation inside the logger box is minimal. Dissipation transforms electric energy into heating energy. It cannot be avoided, but it can be minimized. This source of heating inside the box affects the instrument precision. It is therefore necessary to minimize this amount of heat. Small amounts of heat inside the box do not affect temperature measurements if the openings on the box are quite large so that heat can go out through them. In this way, the temperature in the logger box becomes equal to ambient temperature. With the aim of decreasing dissipation in the box, the logger is not supplied by 230 V AC because of the heating transformer in the logger box. The temperature logger is supplied by the outside power supply of 9 V DC.

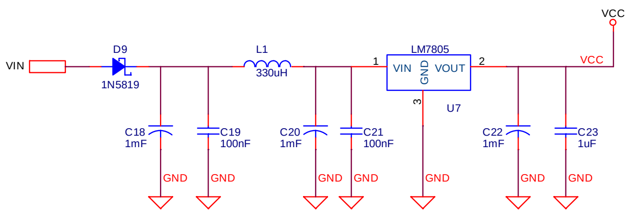

Figure 2. Power supply of the logger

There is high dissipation inside the logger box on the LM7805 linear regulator. The dissipation on the LM7805 can be calculated with the next equation:

$$P_{D,7805} = V_{IN} \cdot I_{IN} - V_{OUT} \cdot I_{OUT} \tag{1}$$

Where:

V_{IN} – input voltage of LM7805

I_{IN} – input current of LM7805

V_{OUT} – output voltage of LM7805

I_{OUT} – output voltage of LM7805

The input current of LM7805 is equal to the sum:

$$I_{IN} = I_{OUT} + I_{LM7805} \tag{2}$$

Where:

I_{LM7805} is a supply current of LM7805

Dissipation can be decreased by decreasing current I_{OUT}. This current can be decreased using optocouplers of lower consumption such as the PC817. These optocouplers are used for galvanic isolation of the serial port. The other way of decreasing dissipation is by decreasing the voltage of the logger power supply. The minimum input voltage of the LM7805 is 7.5 V. The voltage on the protection schottky diode D_9 (Fig.2) is 0.3 V, so the minimum voltage of the logger power supply is 7.8V. Commercial power supply which has voltage nearest to the minimum voltage of the logger power supply is 9V. The current supply of the logger is I_{IN}=60 mA. The dissipation in the logger box is 0.54 W and it is computed by the next equation:

$$P_{D,UK} = V_{PS} \cdot I_{IN} \tag{3}$$

Where:

V_{PS} – voltage of the logger power supply

The supply current of the LM7805 integrated circuit is 8 mA and, using equations (1) and (2), dissipation on the LM7805 is calculated and is equal to 0.26 W.

Functionality of the device

The temperature logger measures instantaneous and average temperatures during programmable time intervals set by the user. This programmable time can be one second minimum and one hour maximum. The schematic presentation of the logger of temperature and its connection with the computer is shown in Fig.3.

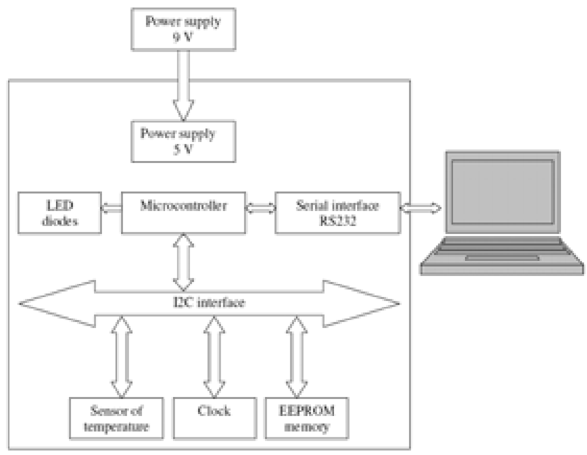

Figure 3. Schematic presentation of the temperature logger

The ATMEGA 8 microcontroller [7] reads temperature values every 0.1 seconds and it averages all measured values during the asserted time interval. The microcontroller then saves these averaged values in the FM24C256 EEPROM memory together with the time of measurement. The measurement time consists of: year, month, day, hour, minute, second and hundredth of seconds. The microcontroller reads time from the PCF8583. The PCF8583 time clock is battery back up, so in case of power cut, the clock continues to measure time. The FM24C256 integrated circuit is memory with a capacity of 32 kB. This memory cans store 4096 events. One event consists of 8 bytes. Seven out of these eight bytes present time and date, and one byte presents average temperature. The ATMEGA 8 microcontroller communicates with the LM75 temperature sensor, the PCF8583 clock and the EEPROM memory by the I2C interface. The I2C interface consists of two lines. One line is for serial data transfer and the other line is for the clock. The I2C interface provides very quick data transfer between the microcontroller and the integrated circuits with the I2C interface. Every integrated circuit with the I2C interface has its own address. The I2C integrated circuits and their line connections are shown in Fig.4.

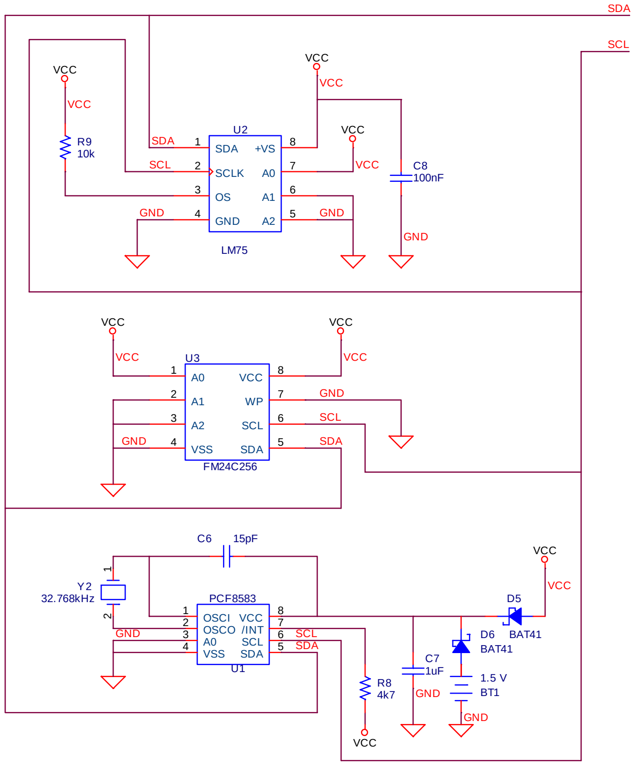

Figure 4. Integrated circuits with the I2C interface in the logger

When the microcontroller needs to communicate with one of the integrated circuits, it first sends the address of that integrated circuit to all integrated circuits with the I2C interface. Every integrated circuit with the I2C interface reads this address and compares it with its own address. Only the integrated circuit with the same address as the address sent by the microcontroller can communicate with the microcontroller. This integrated circuit sends an acknowledging message to the microcontroller that it is ready, and from that moment, data exchange between the microcontroller and that integrated circuit can start.

The PCF8583 integrated circuit consists of a clock and 240 bytes of RAM memory. As the PCF8583 integrated circuit is battery back up, it means that after power is turn off, all data in this RAM memory are saved. Because of this opportunity, this RAM memory is used to control data storage into the EEPROM memory. In this RAM memory, a writing pointer is stored. The writing pointer presents the address of the last written byte in the EEPROM memory. Addresses in the EEPROM memory are sequentially scheduled from address 0 to address 7FFF hex. After every new byte is written in the EEPROM memory, correction of the writing pointer is done. In case power cut occurs, data are saved in the EEPROM memory and the writing pointer is saved in the RAM memory of the PCF8583 which is battery back up. After resetting, the logger is ready to record new 4096 events. This memory is not physically clean. Memory cleaning is done in such a way that the writing pointer is set to start address 0 hex. Thus data still remain in the EEPROM memory, but the microcontroller “sees” that memory is empty by the writing pointer. In case that memory is physically cleaned, it needs about 6 seconds, which is very long time.

For precise temperature measurements, it is necessary to provide that the air flows over all parts of the LM75 integrated circuit. The LM75 integrated circuit exists only in an SMD package. The LM75 integrated circuit is connected with the DIP housing and is set at a short distance from the DIP housing as shown in Fig.5. In that way, air streaming is secured over all parts of the LM75 temperature sensor.

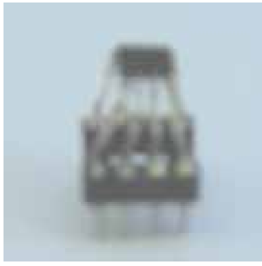

Figure 5. LM75 positioned over the DIP package

The ATMEGA 8 microcontroller controls the functioning of the logger. It operates using a 16 MHz clock. The Brownout detector is inside the microcontroller. It controls the voltage of the microcontroller power supply. If power supply voltage drops below 4 V, the Brownout detector will reset the microcontroller. The improper functioning of the microcontroller is thus prevented in case of power supply cut. The microcontroller is programmed in C program language. The program is installed in the microcontroller flash memory.

The ATMEGA 8 microcontroller has the EEPROM memory in which the parameters of the temperature logger operation are stored. The parameters of the logger operation are:

- logger address
- time of temperature averaging
- baud rate of serial data transfer by the RS232 port

Users set these parameters through a Windows application for the communication with the logger.

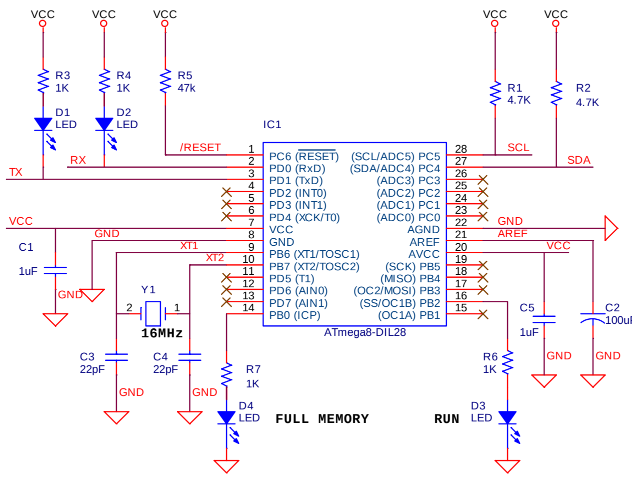

Figure 6. Microcontroller and line connections with the rest of electronics

Every temperature logger has its own address which can be in a range of [0, 254]. In that way more loggers are possible to be connected on the same central computer. The central computer is in the control room. One logger is located in the wind tunnel and the other one is in the room next to the control room where the data acquisition system is. There is often a need for temperature measurement in the air balance calibration room, so the third logger is necessary. It is necessary that at least one byte is used for addressing more devices. It is possible to address 256 devices by one byte. Since at least one byte must be consumed, it is good that this byte is used to a full extent. Therefore, 255 different numbers are dedicated for addressing. Address 255 is the "broadcast" address and it serves for the communication with the logger if the user forgets the address of the logger which was set the last time. All this gives an opportunity for connecting an additional logger to the central computer which can be located elsewhere. The maximum distance which enables the communication between the computer and the device through the RS232serial port is 30 meters on condition that the baud rate is 1200 bit/sec. If a distance longer than 30 meters is required, this logger can be used together with the RS232/RS485 converter. In that case, one RS232/RS485 converter should be connected to the logger and the other RS232/RS485 converter should be connected to the computer. In that way the communication between the logger and the computer is done by the RS485 serial communication. The advantage of the RS485 serial communication is that the maximum distance between the device and the computer is 1,200 meters. This temperature logger is made for wider usage. Time of temperature averaging was set by the user and it can be in the range from 1 second to 1 hour. The user can choose one out of 2 baud rates of the serial port:

- 1200 bit/second
- 9600 bit/second

Galvanic isolation is done in the serial interface of the logger thus protecting the computer. For the realization of galvanic isolation it is not enough to use only optocouplers. The IE0505S 5V/5V DC/DC converter [8] is necessary to enable separated power supply of 5 V on the other side of galvanic isolation (Fig.7).

On their input, some 5V/5V DC/DC converters create noise which propagates onto the 5V power supply line. Better DC/DC convertors use only a capacitor on the input. Poor quality DC/DC convertors must use both a capacitor and an inductor on the input. In that way, the appearance of noise on the 5V input power supply line is prevented. If that inductor is not used and noise exists, that noise can influence temperature measurements thus making them incorrect. The LM75 power supply is used as referent voltage of an A/D converter which is integrated in the LM75. The referent voltage must be constant because of its direct influence on the result of A/D conversion. The inductor L_2, the inductance of which is 100 μH, is therefore used in the serial connection with the capacitor on the input of the DC/DC convertor as shown in Fig.7.

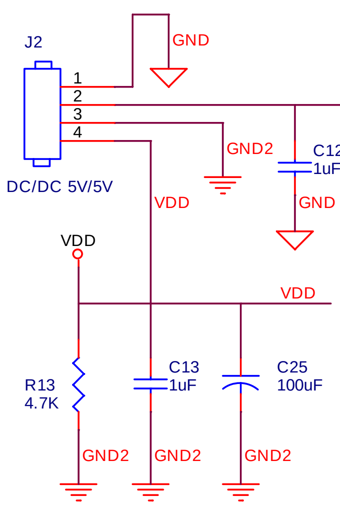

Figure 7. Galvanic isolation of power supply

Optocouplers which have low current supply cannot function at high baud rates. The maximum baud rate of the PC817 optocoupler is 9600 bit/sec. The maximum distance which enables the communication between the computer and the device through the RS232 serial port is 30 meters on condition that the baud rate is 1200 bit/sec. When there is no need for such a long distance, it is better to set the baud rate to 9600 bit/sec because in that way quick data transfer from the logger to the computer is possible. The MAX 232 integrated circuit serves to make level translation from the standard digital voltage level of 0 V and 5 V to the voltage level which corresponds to the RS232 interface. The serial interface of the logger is shown in Fig.8.

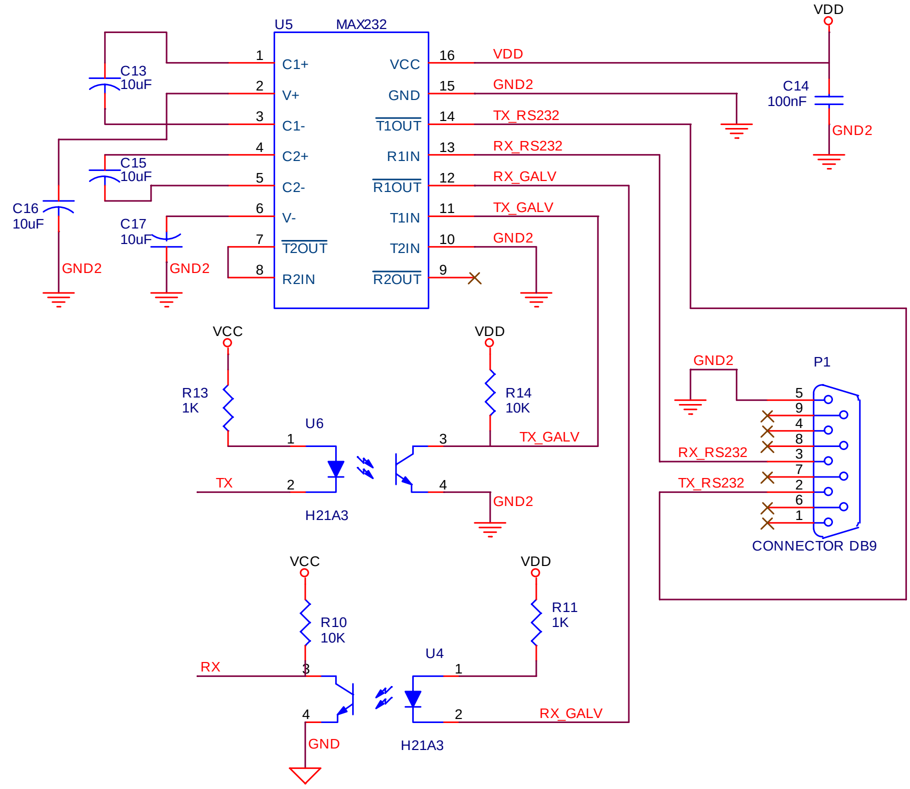

Figure 8. Serial interface of the logger

New portable computers do not have the RS232 port. For that reason, if a new portable computer is used for the communication with the logger, then the RS232/USB converter is necessary.

Red and green LED diodes are intended for checking the communication between the computer and the logger. A LED diode is a very cheap component, but it is very useful in the diagnostics so it should be used whenever possible. A red LED diode indicates sending data from the logger to the computer. A green LED diode indicates receiving data from the computer into the logger. The cathode of the red LED diode is connected to a pin for transmitting data from the serial port of the microcontroller. The anode of the red LED diode is connected to the power supply of 5 V by a "pull up" resistor (Fig.6). The cathode of the green LED diode is connected to a pin for receiving data from the serial port of the microcontroller. The anode of the green LED diode is connected to the power supply of 5 V by a "pull up" resistor (Fig.6).

Application for the communication with the computer

Before starting the communication between the logger and the computer, it is necessary to set the parameters of the serial port. The configuration of the serial port is shown in Fig.9.

The user sets the address of the logger, the name of the serial port and the baud rate of the serial data transfer (9600 bit/sec or 1200 bit/sec). The other parameters of the serial port remain unchanged.

After the configuration of the parameters of the serial port, the user opens the console for the communication with the logger (Fig.10).

The command "LINK RESET" serves for checking the communication between the logger and the computer. The user can set the time and the date from the computer to the logger and can read the time and the date from the logger. The user can set and read the logger parameters. After setting the logger parameters, the logger is reset by a program instruction. After the reset, the logger starts to function with new parameters. The user can reset the logger at any time. After the logger is reset, the logger memory is empty.

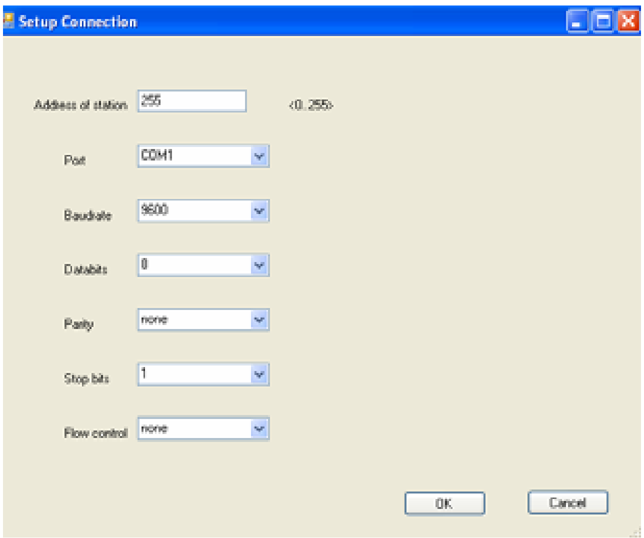

Figure 9. Configuration of the serial port

The user can read recorded data from the logger as well as instantaneous temperature. Fig.11 shows the results recorded by the logger and transferred to the computer.

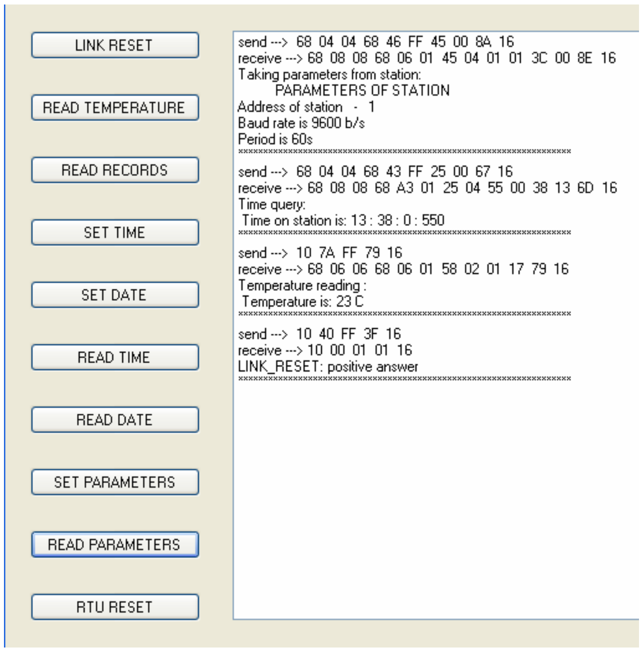

Figure 10. Console for the communication with the logger

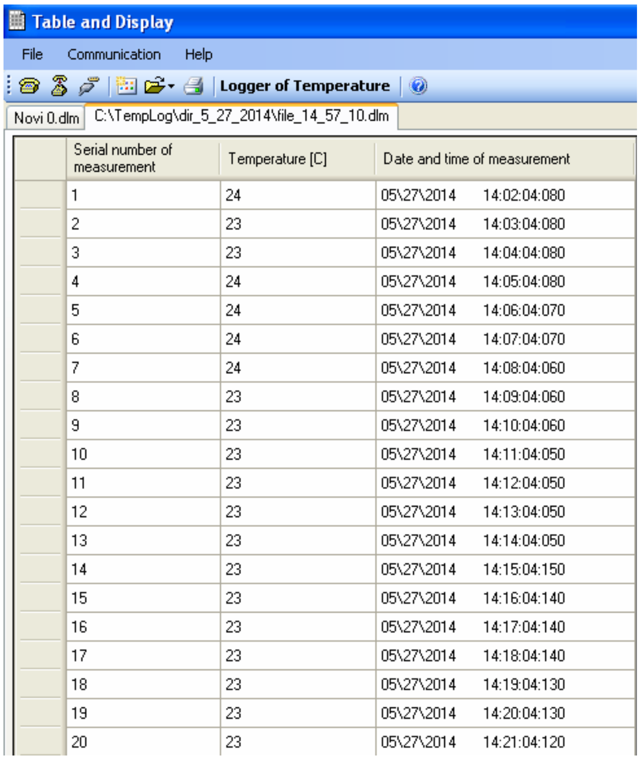

Table and Display
File Communication Help
Logger of Temperature
Novi 0.dlm C:\TempLog\dir_5_27_2014\file_14_57_10.dlm

Serial number of measurement	Temperature [C]	Date and time of measurement	
1	24	05\27\2014	14:02:04:080
2	23	05\27\2014	14:03:04:080
3	23	05\27\2014	14:04:04:080
4	24	05\27\2014	14:05:04:080
5	24	05\27\2014	14:06:04:070
6	24	05\27\2014	14:07:04:070
7	24	05\27\2014	14:08:04:060
8	23	05\27\2014	14:09:04:060
9	23	05\27\2014	14:10:04:060
10	23	05\27\2014	14:11:04:050
11	23	05\27\2014	14:12:04:050
12	23	05\27\2014	14:13:04:050
13	23	05\27\2014	14:14:04:050
14	23	05\27\2014	14:15:04:150
15	23	05\27\2014	14:16:04:140
16	23	05\27\2014	14:17:04:140
17	23	05\27\2014	14:18:04:140
18	23	05\27\2014	14:19:04:130
19	23	05\27\2014	14:20:04:130
20	23	05\27\2014	14:21:04:120

Figure 11. Recorded data by the logger

Processing the measurement data

The measurement results given in the Table in Fig.11 are used for the estimation of the measurement uncertainty. Temperature measurements are carried out every minute and there are 20 values of measurements. The room is closed and the temperature in the room does not change during the measurement. The average value of a specimen is given by the next equation:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{4}$$

Where:
n – number of measurements
x_i – value of measurement

The average measurement value is obtained by replacing the measurement values in equation (4) and it is equal to $\overline{x}$ =23.25°C.

The standard specimen deviation measures the amount of the variation of the average value. It is defined by the next equation:

$$s=\sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2} \tag{5}$$

In this case, the standard deviation of the specimen is equal to s=0.44°C.

Measurement uncertainty is a non-negative parameter which characterizes the dispersion of the values of the measured quantity. It is given by the next equation:

$$C=\frac{s}{\sqrt{n}}=\sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2} \tag{6}$$

The assumption is that the exact measurement value is equal to the average value of the measured values. Measurement uncertainty is obtained by replacing the average value x_0 and the measurement values x_i in equation (5) and it is equal to C=0.1°C. This procedure makes sense only if the number of measurements n is higher than 10.

Conclusion

The LM75 temperature sensor has a precision of ±3°C in the range [-55°C, 125°C]. It has a precision of ±2°C in the range [-25°C, 100°C]. This information is given in the datasheet of the LM75 temperature sensor [6]. It can be seen from these data that with decreasing a temperature range, the precision of temperature measurement increases. This precision of the LM75 temperature sensor is the consequence of the linearization of the nonlinear characteristics of an NTC thermistor integrated in the LM75. The comparison of the results of temperature measurements done by the temperature logger and by a platinum resistance thermometer shows that all the measurement results have precision which is less than or equal to the defined 2°C in the range [-25°C, 100°C].

The BOE440 box used for the temperature logger has openings which enable air streaming. The second advantage of this box is that the box shutter can be taken off very easily without disturbing the logger functioning. The temperature inside the box becomes equal to the ambient temperature by taking off the box shutter. It is found out that the temperature logger measures temperature as 1°C higher in the closed box than when the shutter is taken off.

There is the opportunity for additional research in order to further decrease dissipation in the logger box. Instant dissipation inside the logger is 0.54 W. Dissipation can be decreased if a power supply of 5 V is pulled out from the logger box. In that way, there will be half less dissipation in the box and the temperature inside the logger box will be the same as ambient temperature.

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Uređaj za daljinsko merenje i snimanje temperature

U ovom radu je predstavljen uređaj za daljinsko merenje i snimanje temperature. Loger temperature je uređaj koji meri srednju vrednost temperature tokom zadatog vremenskog intervala i upisuje srednju vrednost temperature u memoriju zajedno sa vremenskim trenutkom merenja. Uređaj ima serijski port RS232 pomoću kojeg se snimljeni podaci šalju na računar i pomoću kojeg je omogućeno daljinsko merenje temperature. Aplikacija za komunikaciju između računara i logera temperature je napisana u C# programskom jeziku.

Ključne reči: **merenje temperature, daljinsko merenje, loger.**

Устройство для дистанционного измерения и регистрации температуры

Эта статья представляет собой устройство для дистанционного измерения и для регистрации температуры. Регистратор температуры представляет собой устройство, которое измеряет среднюю температуру в течение заданного интервала времени, и средняя температура вводится в память, а также и одновременно момент измерения. Устройство имеет последовательный порт RS232, через который записанные данные передаются на компьютер и, при помощи которого позволено дистанционное измерение температуры. Применение для связи между компьютером и регистратором температуры написано на C # языке программирования.

Ключевые слова: **измерение температуры, дистанционное измерение, регистратор.**

Dispositif pour le mesurage et l'enregistrement de la température à distance

Dans ce papier on a présenté le dispositif pour le mesurage et l'enregistrement de la température à distance. L'enregistreur de la température est un instrument qui mesure la valeur moyenne de température au cours de l'intervalle temporelle déterminée et qui inscrit cette valeur moyenne de température dans la mémoire ensemble avec le moment temporel de mesurage. Le dispositif a le port de série RS 232 par lequel les données enregistrées sont envoyées sur l'ordinateur et par lequel le mesurage de température à distance est possible. L'application pour la communication entre l'ordinateur et l'enregistreur de température est écrite dans la langue de programmation C #.

Mots clés: **mesurage de température, mesurage à distance, enregistreur.**