Generalized Net Model of a Body Temperature Data Logger Embedded System

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Abstract: This paper represents a prototype embedded system, intended for measuring, gathering and transmitting the obtained data of the temperature of the skin and the ambient air. The system is designed to collect data in relatively short intervals, for fairly long periods of time. The skin temperature measurements are performed using an infrared temperature sensor. Some experimental results are also presented.

Keywords: Core body temperature, Generalized nets, Embedded system.

Introduction
Continuously monitoring of core body temperature suggests measuring device to be placed on, so as not to interfere and not to bother the patient. The classical methods for measuring the core body temperature, in particular the non-invasive methods, would not be adequate for this purpose. Although the skin temperature is not a reliable method [1, 6] to estimate the core body temperature, we decided to attempt to find dependencies between body skin and environment temperatures, and conceivably the core body temperature. Assuming that such a device should be worn constantly, we decided to turn our attention to measuring the temperature of the skin of the arm, as well as the surrounding air temperature. The developed Generalized net model would be helpful in case of increasing the number and the type of the temperature sensors, as well as when using a different microcontroller.

Embedded system overview
The system comprises two separate temperature sensors and a microcontroller. In Fig. 1 and Fig. 2 are shown the simplified structures of the used sensors.

Fig. 1 Simplified block diagram of DS18B20 temperature sensor
The first one, DS18B20 [4] (Fig. 1), is used for measuring the environment temperature. The second one, MLX90614 [5] (Fig. 2) measures the infrared radiation against the sensor (in this case, the skin temperature). The communication between the sensors and the microcontroller is implemented via two separate serial communication busses: 1-Wire and I2C.

Due to the large number of measurements are expected, the external EEPROM (Electrically Erasable Programmable Read Only Memory) memory is used. This external memory also uses the I2C bus (Fig. 3). The communication between embedded system and the PC is established via serial communication interface (SCI).

During most of the time, the system operates in a low-power mode, i.e. the microcontroller unit (MCU) is in a “sleep” mode, the main (internal) oscillator is off. In this mode, only the Timer1 oscillator is active. When the Timer1 counter is overflowed, the interrupt is generated, the main oscillator is turned on and the system wakes up. During the active mode, the temperature data are read from the sensor and stored in the external EEPROM memory. Then, if there is a request from the external device (PC), all data, stored in the external memory, is transmitted via SCI interface. Then, the MCU goes into sleep mode, until the next Timer1 interrupt.
Fig. 4 shows the principle of the data arrangement in the external EEPROM memory. At the first two cells (addresses 00H and 01H) is stored the address of the memory cell, where should be stored the first byte of the next data readings. Since every data reading is summarized in four bytes, after each subsequent reading, the content of the first two cells is increased by 4. After whole memory space write, the oldest data record is overwritten.

When the whole memory data are transmitted to the computer system, it is rearranged, so the first data reading would be the data from the address, previous to the address, written in the first two memory cells. Knowing the time of the transmitting and the period between each temperature measurements, it is easy to draw a time dependent temperature graph. Furthermore, the data are recalculated, according to the manufacturer’s specifications [1, 4], as follows:

$$T_{obj} = 0.02 (256 \cdot t_{objH} + t_{objL}) - 273,$$

where $T_{obj}$ is the temperature obtained from the MLX90614 temperature sensor (skin temperature), $t_{objH}$ and $t_{objL}$ are respectively the Most Significant Bits (MSB) and the Least Significant Bits (LSB) data values.

$$T_{env} = 16 \cdot t_{envH} + (t_{envL} \gg 4) + (t_{envL} \& 0b00001111)/16,$$

where $T_{env}$ is the temperature obtained from the DS18B20 temperature sensor (air temperature), $t_{envH}$ and $t_{envL}$ are respectively the MSB and the LSB data values.

**Generalized net model**

All definitions related to the concept of Generalized nets are taken from [2, 3]. The net describing the work of the embedded system is shown in Fig. 5.

Initially the following tokens enter the generalized net:
- in place $S_{12} - \alpha$-token with characteristic “Timer1 value”;
- in place $S_{73} - \beta$-token with characteristic “Array of temperature data”.
The generalized net is presented by the following set of transitions:

\[ A = \{ Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7 \} \]

The particular transitions describe the following processes:
- \( Z_1 \) – Timer1 counting;
- \( Z_2 \) – Sensor data reading;
- \( Z_3 \) – Calculating the next EEPROM address for writing;
- \( Z_4 \) – SCI routines;
- \( Z_5 \) – Calculating the next EEPROM address for reading;
- \( Z_6 \) – Read/Write data from/to EEPROM;
- \( Z_7 \) – Converting the data and storing in array.

Fig. 5 GN model of the temperature data logger system

The transitions have the following description:

\[ Z_1 = \langle \{ S_{12} \}, \{ S_{11}, S_{12} \}, R_1, \lor(S_{12}) \rangle \]

\[ R_1 = \frac{S_{11}}{S_{12}} \cdot \frac{S_{12}}{S_{11}} \cdot \frac{S_{12}}{W_{12,11}} \cdot \text{True} \]

where \( W_{12,11} = \text{“T1IF = 1”} \) (T1IF – Timer1 Interrupt Flag).

The token that enters place \( S_{12} \) obtains characteristic “Timer1 value”. The token that enters place \( S_{11} \) obtains characteristic “Interrupt flag”.

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\[ Z_2 = \langle \{S_{11}, S_{22}\}, \{S_{21}, S_{22}\}, R_2, \lor(S_{11}, S_{22}) \rangle \]

\[
\begin{array}{c|cc}
R_2 & S_{21} & S_{22} \\
\hline
S_{11} & false & true \\
S_{22} & W_{22,21} & W_{22,22}
\end{array}
\]

where \( W_{22,21} = "The sensor data are read"; \)
\( W_{22,22} = \neg W_{22,21}. \)

The token that enters place \( S_{22}, \) from place \( S_{11}, \) obtains characteristic “Temperature sensor device address”.

The token that enters place \( S_{21}, \) obtains characteristic “Current temperature data”.

\[ Z_3 = \langle \{S_{21}, S_{33}\}, \{S_{31}, S_{32}, S_{33}\}, R_3, \lor(S_{21}, S_{33}) \rangle \]

\[
\begin{array}{c|ccc}
R_3 & S_{31} & S_{32} & S_{33} \\
\hline
S_{21} & true & false & true \\
S_{33} & false & \ W_{33,32} & true
\end{array}
\]

where \( W_{33,32} = "The next address for writing is calculated". \)

The token from place \( S_{21}, \) enters place \( S_{31}, \) where does not change its characteristic, and place \( S_{33}, \) where obtains characteristic “EEPROM address”.

The token that enters place \( S_{32}, \) obtains characteristic “EEPROM address and temperature data”.

\[ Z_4 = \langle \{S_{31}, S_{42}, S_{61}\}, \{S_{41}, S_{42}\}, R_4, \lor(S_{31}, S_{42}, S_{61}) \rangle \]

\[
\begin{array}{c|cc}
R_4 & S_{41} & S_{42} \\
\hline
S_{31} & false & true \\
S_{42} & W_{42,41} & W_{42,42} \\
S_{61} & false & true
\end{array}
\]

where \( W_{42,41} = "TRMT = 1" (TRMT – Transmitter Buffer Empty Flag); \)
\( W_{42,42} = \neg W_{42,41}. \)

The token from place \( S_{31}, \) enters place \( S_{42}, \) and does not change its characteristic.

The token from place \( S_{61}, \) enters place \( S_{42}, \) and does not change its characteristic.

The token that enters place \( S_{41}, \) obtains characteristic “SCI transmitted data”.

\[ Z_5 = \langle \{S_{53}, S_{72}\}, \{S_{51}, S_{52}, S_{53}\}, R_5, \lor(S_{53}, S_{72}) \rangle \]
The token that enters place $S_{51}$ obtains characteristic “Sleep instruction”.

The token that enters place $S_{52}$ obtains characteristic “Next address”.

The token that enters place $S_{53}$, from place $S_{72}$, obtains characteristic “Start address”.

$Z_6 = \langle \{s_{32}, s_{52}, s_{63}\}, \{s_{61}, s_{62}\}, R_6, \lor(s_{32}, s_{53}, s_{62}) \rangle$

$R_6 = \begin{array}{c|ccc}
S_{32} & S_{61} & S_{62} \\
false & true & \\
S_{52} & false & true \\
S_{62} & W_{62,61} & true
\end{array}$

where $W_{62,61} = "The maximum EEPROM address is reached"$.

The token from place $S_{32}$ enters place $S_{63}$, and does not change its characteristic.

The token from place $S_{52}$ enters place $S_{63}$, and does not change its characteristic.

The token that enters place $S_{61}$ obtains characteristic “Data read from EEPROM”.

$Z_7 = \langle \{s_{41}, s_{73}\}, \{s_{71}, s_{72}, s_{73}\}, R_7, \lor(s_{41}, s_{73}) \rangle$

$R_7 = \begin{array}{c|ccc}
S_{41} & S_{71} & S_{72} & S_{73} \\
false & false & true \\
S_{71} & W_{73,71} & W_{73,72} & true
\end{array}$

where $W_{73,71} = "The temperature data are recalculated, rearranged and stored in the array"$; $W_{73,72} = "There is a request for a whole EEPROM data reading"$.

The token that enters place $S_{71}$ obtains characteristic “Array with recalculated temperature data”.

The token that enters place $S_{72}$ obtains characteristic “EEPROM read request”.

The token from place $S_{41}$ enters place $S_{73}$, and does not change its characteristic.

**Results and discussion**

We conducted a number of measurements, placing the sensors at various locations on the arm, at different ambient air temperatures, and for different time durations. In Fig. 6 is shown a
graph of one of those measurements. These are raw data (there is no additional data processing), obtained by continuous measurements, within about five hours. The graph represents the variations of the skin temperature, given that the infrared sensor was placed just above the elbow, touching the skin. The air temperature sensor was placed about an inch above the skin. The measurements until around 220th minute are made in clothed state of the arm, while the remaining measurements are made with direct exposure to the ambient air.

Fig. 6 The temperature of the skin and the temperature near the skin (around an inch)

Conclusion
The prototype of the system is realized and experimental results are obtained. To establish reliable dependencies between temperature of the particular place on the skin and core body temperature, it would be necessary to perform additional measurements. The measurement of the temperature of the ear canal would be the most convenient method to obtain these reference data.

References
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