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Intelligent Instrumentation Approach to Semiconductor Temperature Measurement by Analogue Transmission Using a Z80 Microcomputer

A.A. Adegbemile
Department of Electrical and Electronic Engineering, Faculty of Engineering,
University of Ado Ekiti, Ekiti State, Nigeria

Abstract: A Z80 microcomputer based instrumentation which makes use of semiconductor transducer, analogue to digital converter and which samples temperatures at 1 min interval at a point where it may vary in the range of 0-100°C was examined. The 8 bit binary code output of the Analogue to Digital Converter (ADC) and the corresponding temperature values were obtained with an input voltage range of 0-8V increased at an interval of 0.5 V. The ADC total levels of 256 and the resolution of 31.25 mV were determined. A hierarchical decomposition diagram, a proper structural description and a pseudo-code description of the modules of the software routines at all levels were developed to store the 256 temperature values and compute the highest, lowest, average and the number of temperature which exceed 50°C.

Key words: Temperature, transducer, analogue to digital converter, measurement and Z80 microprocessor

INTRODUCTION

Intelligent instrumentation is a term which has come to means the use of a measurement system to evaluate a physical variable employing usually a digital computer to perform all or nearly all the signal information processing (Barney, 1988). The advent of microprocessor has provided the means of adding intelligence (albeit of artificial nature) to many everyday facilities. These range form cash dispensers point of sales check outs, washing machines, burglar alarm, motor vehicle and various instruments (Barney, 1988). In the present microprocessor based systems, most of the operations are software oriented and hence the flexibility (Chaudary *et al*., 1989). Z80 microprocessor is the most popular 8 bit processor in industrial applications and has more processing instructions (Harland, 1990).

Temperature is one of the most frequently measured physical variables (Hencke, 1989). Temperature is a variable which generally changes slowly (Freitas, 1980). Its measurement is very common and is known to make heavy demands on equipment and computer processing. Its use in instrumentation and control is significant (Yong, 1983). In the present sophisticated world, sensors and actuators forms a vital part of any measuring and controlling systems (Mayak *et al*., 1989). Thermocouples, resistance temperature detectors and thermistors are well tried and reliable methods. Recently a new generation of semiconductor devices have emerged which shows considerable promise. The semiconductor devices include linearization circuits and operational amplifiers (Yong, 1983). Although, non linearity is relatively unimportant in modern transducers, since, one, they are usually interfaced to a computer system and the non-linearity removed by a look up table and two linearization of transducer characteristics can been achieved by mathematical manipulations and interactive computations involving a digital computer (Ghosh and Patranabis, 1989). Analogue to digital converters ADCS converts information from analogue form to digital form (Hencke, 1989). The ADCS perform two basic operations, quantization and coding. Quantization is the mapping of a continuous signal into one of several possible discrete ranges or quanta, coding is the assignment of a binary code to each discrete range (Short, 1981). The actions of sampling and holding are mathematically significant (Usher and Keating, 1996). In this microprocessor based instrumentation system the signal is converted to processing systems which include the following elements, semiconductor transducer, analogue to digital converter, interface to a Z80 microprocessor. The program hierarchical decomposition diagrams and proper structural description diagram and pseudo-code description of the modules of the software routines at all levels and finally the look up table.

MATERIALS AND METHODS

Hardware: The hardware components are:

Figure 1 shows a Z80 microcomputer based instrumentation system which samples temperature at 1 min intervals at a point where it may vary in the range of 0-100°C. The relationship between the temperature and the analogue voltage Vx is non-linear as shown by the calibration curve in Fig. 2.

The ADC has an input range of 0-8 V and produces an 8 bits binary code output. In a particular measuring period of 100 min, the temperature reading are taken into the Z80 microcomputer and stored in memory starting at address 1000H.

Software: The program hierarchical decomposition diagram and structural description and pseudo code description of the modules of the software routines at all levels was carried out. The look up table of the 256 temperature values was obtained from the calibration curve showing the relationship between temperature and the analogue voltage Vx in Fig. 2. This is to enable

- Semiconductor temperature transducer
- Analogue to Digital Converter (ADC)
- A Z80 micro computer
- The storage of 256 temperature values in the look up table in Table 1 in Z80 microcomputer memory starting at address 1000H.

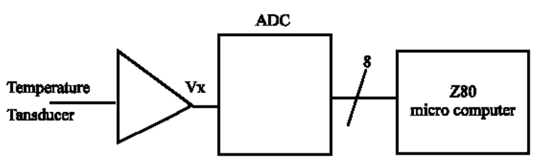

Fig. 1: Z80 microcomputer based instrumentation

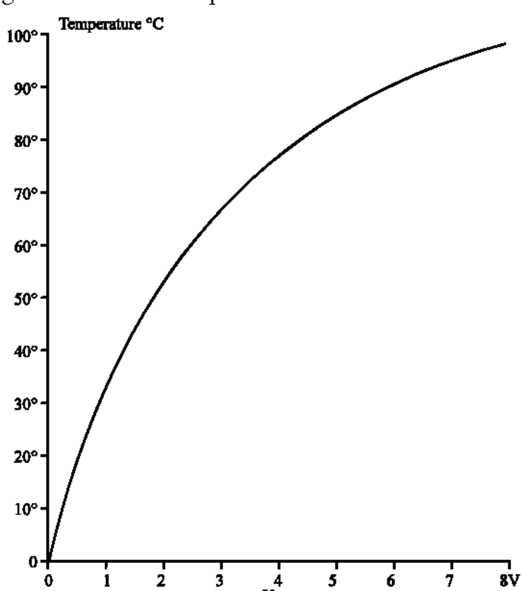

Fig. 2: The relationship between the temperature and the analogue voltage

- The computation of the following datas in the form of 8 bit binary numbers stored at symbolic addresses.

If an assembly language programmed is developed in Z80 microprocessor

Address	Data
AVGE	Average temperature
Max	Highest temperature
Min	Lowest temperature
Number	The temperature value which exceeds 50°C

Analysis: The relationship between temperature and analogue voltage Vx is non linear as shown by the calibration curve in Fig. 2.

However, if a small portion of the curve is considered and linearity is assumed over that small portion, small change in temperature = δT results in a small change in analogue voltage = δVx

Therefore, temperature = mVx + C

Where $m = \frac{\delta T}{\delta V_x}$ = the gradient and

C is the current temperature

The ADC has an input voltage range of 0-8 V and produces an 8 bits output.

For an 8 bit output code,

The total number of levels = $2^8 = 256$

Therefore the resolution = 8/256 = 31.25 mv, the 8 bits output is shown in Fig. 3 with the integer and the fractional part.

Table 1: ADC input voltage, ADC binary coded output and corresponding temperature values

ADC input V	ADC output	ADC output In binary code	Temperature O°C
0	0	0	0
0.5	16	00010000	20
1.0	32	00100000	33.75
1.5	48	0011000	45.625
2.0	64	01000000	54.375
2.5	80	01010000	61.25
3.0	96	01100000	68.75
3.5	112	01110000	73.75
4.0	128	10000000	79.375
4.5	144	10010000	83.75
5.0	160	10100000	87.5
5.5	176	10110000	90.0
6.0	192	11000000	92.5
6.5	203	11010000	95.0
7.0	224	11100000	97.5
7.5	240	11110000	99.375
8	256	11111111	100.0

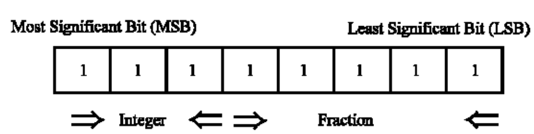

Fig. 3: Integer and fractional part

Table 2: Look up table of input voltage and corresponding temperature values

Volt (mV)	Temp (⁰C)	Volt (V)	Temp (⁰C)	Volt (V)	Temp (⁰C)	Volt(V)	Temp (⁰C)
31.25	1	1.03125	35	2.03125	55	3.03125	69
62.5	2	1.0625	36	2.0625	56	3.0625	69
93.75	3	1.09375	36	2.09375	56	3.09375	69
125.0	4	1.125	37	2.125	56	3.125	70
156.25	5	1.15625	37	2.15625	57	3.15625	70
187.5	6	1.1875	38	2.1875	57	3.1875	70
218.75	8	1.28125	39	2.21875	57	3.21875	70
250.0	9	1.250	40	2.250	58	3.250	71
281.25	10	1.28125	40	2.28125	59	3.28125	71
312.5	11	1.3125	41	2.3125	59	3.3125	71
343.75	12	1.34375	41	2.34375	60	3.34325	71
375.0	13	1.375	42	2.375	60	3.375	72
406.25	14	1.40625	43	2.40625	60	3.40625	72
437.5	15	1.4375	43	2.4375	61	3.4375	72
468.75	16	1.46875	44	2.46875	61	3.46875	73
500.0	17	1.500	45	2.500	62	3.500	73
531.25	18	1.5313	45	2.5313	62	3.5313	73
562.5	20	1.5625	46	2.5625	63	3.5625	73
593.75	21	1.5935	47	2.5938	63	3.5938	74
625.0	22	1.625	47	2.625	63	3.625	74
656.25	23	1.6563	48	2.6563	64	3.6563	74
687.5	24	1.6875	49	2.6875	64	3.6875	74
718.75	25	1.7188	49	2.7188	65	3.7188	75
750	26	1.750	50	2.750	65	3.750	75
781.25	27	1.7813	51	2.7813	66	3.7813	75
812.5	28	1.8125	51	2.8125	66	3.8125	75
843.75	29	1.84375	52	2.84375	67	3.84375	75
875.0	30	1.875	52	2.875	67	3.875	76
906.25	32	1.90625	53	2.90625	67	3.90625	76
937.5	33	1.9375	54	2.9375	68	3.9375	76
968.75	34	1.96875	54	2.96875	68	3.96875	77
1000	34	2.000	55	3.00	68	4.000	77

Table 2 (Continued): Look up table of input voltage and corresponding temperature values

Volt (V)	Temp (⁰C)	Volt (V)	Temp (⁰C)	Volt (V)	Temp (⁰C)	Volt (V)	Temp (⁰C)
4.03125	77	5.03125	88	6.03125	93	7.03125	97
4.0625	78	5.0625	88	6.0625	93	7.0625	97
4.09375	78	5.09375	88	6.08375	93	7.08375	97
4.125	78	5.125	88	6.25	93	7.125	97
4.15625	79	5.15625	88	6.15625	94	7.15625	97
4.1875	79	5.1875	89	6.1875	94	7.1875	97
4.21875	79	5.21875	89	6.21875	94	7.21875	97
4.250	80	5.250	89	6.250	94	7.250	97
4.28125	80	5.28125	89	6.28125	94	7.28125	97
4.3125	80	5.3125	89	6.3125	94	7.3125	97
4.34325	80	5.34325	90	6.34370	94	7.34375	98
4.375	81	5.375	90	6.375	95	7.375	98
4.40625	81	5.40625	90	6.40625	95	7.40625	98
4.4375	81	5.4375	90	6.4375	95	7.4375	98
4.46875	82	5.46875	90	6.46875	95	7.46875	98
4.500	82	5.500	91	6.500	95	7.500	98
4.5313	83	5.5313	91	6.5313	95	7.5313	98
4.5625	83	5.5625	91	6.5625	95	7.5625	98
4.5938	84	5.5933	91	6.5933	95	7.5933	98
4.625	84	5.625	91	6.625	95	7.625	98
4.6563	84	5.6563	92	6.6563	95	7.6563	98
4.6875	85	5.6875	92	6.6875	95	7.6875	99
4.7188	85	5.7188	92	6.7188	96	7.7188	99
4.750	86	5.750	92	6.750	96	7.750	99
4.7813	86	5.7813	92	6.7813	96	7.7813	99
4.8125	86	5.8125	92	6.8125	96	7.8125	99
4.84375	86	5.84375	93	6.84375	96	7.84375	99
4.875	87	5.875	93	6.875	96	7.875	100
4.90625	87	5.90625	93	6.90625	96	7.90625	100
4.9375	87	5.9375	93	6.9375	96	7.9375	100
4.96875	87	5.96875	93	6.96875	96	7.96775	100
5.000	87	6.000	93	7.00	96	8.00	

Fig 4: Binary code representing 0.5 V

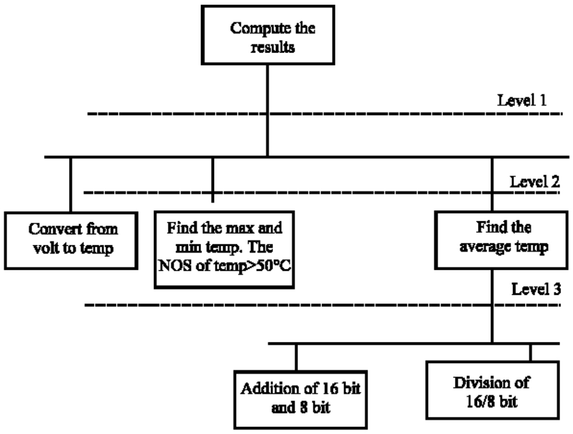

Fig. 5: Hierarchical decomposition diagram

With an input voltage range of 0-8V and an incremental voltage of 0.5 V starting from 0 V. The corresponding 8 bit binary code and corresponding temperature values as obtained from the calibration curve in Fig. 2 are shown in Table 1.

Example: If the input voltage Vx into the ADC is 0.5 V. This corresponds to 2^4=16 at the ADC output, which is represented by 00010000 as shown in Fig. 4.

Look up table: With an incremental voltage of 31.25 mV starting from 0V as input to the ADC. The ADC corresponding temperature values were obtained from the calibration curve in Fig. 2 to give the required 256 temperature values as shown up in the look up table in Table 2.

SOFTWARE DEVELOPMENT

Decomposition diagram: The hierarchical decomposition diagram is shown in Fig. 5.

STRUCTURAL DESCRIPTION OF THE PROGRAM

LEVEL 1:

```
BEGIN (MAIN PROGRAM)
    INITIALIZE MAX TEMPERATURE
    INITIALIZE NUMBER OF TEMPERATURE > 50⁰C
    INITIALIZE MEAN TEMPERATURE
    INITIALIZE TOTAL TEMPERATURE
    INITIALIZE MIN TEMPERATURE
    SET VOLT POINTER
    SET TEMPERATURE TABLE POINTER
    GET VOLT
    GET TEMPERATURE
    SAVE TEMPERATURE IN VOLT SOURCE
    SAVE TEMPERATURE
    CALL MAX H
    CALL NUMBER
    CALL TOTAL E
    CALL MIN L
    POINT TO NEXT VOLT
    GET NUMBER
    IF NUMBER > POINTED NUMBER
        THEN
                CONTINUE
        ELSE
                CALL MEAN
        END IF
END
```

LEVEL II:

```
BEGIN     (TO FIND MINIMUM TEMPERATURE)
    GET (MIN)
    GET (TEMPERATURE)
    IF (TEMPERATURE) < (MIN)
    THEN
    (MIN) = (TEMPERATURE)
    ELSE
    RESTORE (MIN)
    END IF
END

BEGIN     (TO FIND MAXIMUM TEMPERATURE)
GET (MAXIMUM)
    GET (TEMPERATURE)
    IF (TEMPERATURE) > (MAXIMUM)
        THEN
            (MAXIMUM) = (TEMPERATURE)
        ELSE
            RESTORE (MAXIMUM)
        END IF
END

BEGIN     (TO FIND NUMBER OF TEMPERATURE>50⁰)
    CLEAR COUNTER
    GET NUMBER
    GET (TEMPERATURE)
    IF (TEMPERATURE)>(NUMBER)
        THEN
            INCREMENT COUNT
        ELSE
            RESTORE COUNT
        END IF
END

BEGIN     (TO FIND THE SUM OF THE TEMPERATURE VALUES
          STORED IN MEMORY LOCATION (1000H-1064H)
    GET TOTAL
    GET (TEMPERATURE)
    TOTAL= (TOTAL) + (TEMPERATURE)
END

BEGIN     (TO FIND THE AVERAGE TEMPERATURE)
    GET DIVIDENT
    GET DIVISOR
    SET LOOP = 8
    DO UNTIL LOOP=0
        SHIFT DIVIDENT LEFT
        CLEAR C
        DIVIDE OUT
        SET QUOTIENT =1
        IF CARRY SET
            THEN
```

```
                RESTORE DIVIDENT
          ELSE
                DECREMENT LOOP
          END IF
          END DO
          SAVE RESULT
END

BEGIN     (APROGRAM OF THE LOOP UP TABLE WHICH
          CONTAIN THE 256 VALUES OF THE TEMPERATURTE
          OBTAINED FROM THE GRAPH OF TEMPERATURE
          AGAINST VOLTAGE) is
PSEUDO CODE DESCRIPTION OF THE PROGRAM
TO COMPUTE AVGE
AVERAGE = 0
POINTER=1000H
LOOP= 64H
DO UNTIL LOOP =0
          AVERAGE = AVERAGE + TEMPERATURE
          LOOP= LOOP – 1
END DO
```

$$AVERAGE = \frac{Average}{64H}$$

```
END

TO COMPUTE LOWEST, HIGHEST AND THE NUMBER OF
TEMPERATURE>50⁰C
DATA= 1000H
HIGHEST = 0
LOWEST = 0
NUMBER = 0
DO UNTIL DATA = 1064H
     IF TEMPERATURE < LOWEST THEN
          LOWEST = TEMPERATURE
     ELSE
          IF TEMPERATURE > HIGHEST THEN
          HIGHEST = TEMPERATURE
     ELSE
          IF TEMPERATURE >50⁰C THEN
                NUMBER = NUMBER + 1
     ELSE CONTINUE
     END DO
END

ADDITIONAL ROUTINE
ADD 8 BIT NUMBER TO 16 BIT NUMBER
RESULT B = 0                              16 BIT
RESULT A = 0                              8 BIT
NUMBER   = 0
BEGIN
     CARRY = 0
     RESULT A = RESULT A + NUMBER
     IF CARRY = 1 THEN (THE FLAG IS SET)
          RESULT B = RESULT B + 1
          ELSE CONTINUE
END
```

RESULTS AND DISCUSSION

The relationship between temperature and the analogue voltage V_x as shown by the calibrator curve is non linear. With an input voltage range of 0-8 V, an incremental voltage of 0.5 V was applied to the input of ADC starting from 0V and the corresponding temperature values were obtained from the calibration curve.

They are as shown in Table 1. The temperature value increases with increase in the analogue voltage to the input of the analogue to digital converter. The integer values of the ADC output are the three most significant bits of the 8 bit output of ADC and the fractional values are the remaining 5 bits.

The ADC total levels and the resolution were found to be 256 levels and 31.25 mV.

The look up table in Table 2 is obtained from the calibration curve using the resolution of 31.25 mV as the incremental voltage value starting from 0V to obtain the corresponding temperature values. These amount to 256 temperatures values.

In Table 2, with a resolution of 31.25 mV as incremental analogue input voltage to the analogue to the digital converter, the temperature increases linearly until the input analogue voltage was 1.0V.

At above 1.0V input voltage up till 4.71880 V, the non linearity in the increase in temperature is less critical.

At 4.750 V-5.8125 the non linearity in the increase in temperature becomes critical.

At 5.84375 V-8.00 V, the non linearity in the increase in temperature becomes more critical.

The importance of the look up table is to remove the effect of the non-linearity in transducers.

A decomposition diagram, a proper structural description and pseudo code description of the modules of the program at all levels was developed to store the 256 temperature values in Z80 microcomputer and to compute the highest (maximum), the lowest (minimum), the Average (AVGE) and the number of temperature same exceed 50°C (NUMBER).

CONCLUSION

A Z80 Microcomputer based instrumentation which samples temperature at 1 min interval at a point where it may vary in the range of 0-100°C was examined. The instrumentation system makes use of a semiconductor transducer and an analogue to digital converter. The ADC has an input voltage range of 0-8V and an 8 bit output.
The following conclusions are made:

- The three most significant bits of the ADC output are the temperature integer values and the remaining five bits are the fractional value.
- There are a total of 256 ADC levels and as such 256 temperature values.
- The resolution of the ADC is 31.25 mV.

- The temperature increased linearly with increase in the input voltage up till 1V. At above 1V the non linearity manifests.
- A decomposition diagram, a proper structural description and pseudo code description of the modules was developed to store the 256 temperature values in Z80 microcomputer and to compute the highest(maximum), the lowest(minimum), the average (AVGE) and the number of temperature values which exceed 50°C (Number).

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