Design and Implementation of Ultrasonic Based Distance Measurement Embedded System with Temperature Compensation

Rawaz H. Abdullah

Abstract- ***This work presents the design and practical implementation of an embedded system which can measure temperature of the environment and uses an ultrasonic sensor to measure the distance of objects ranging from 2 cm to 400 cm. The measured temperature is compensated to find the speed of the ultrasonic wave to obtain a more accurate distance measurement. The heart of the embedded system is a low-cost, low-power, and high-performance ATmega328P microcontroller from Atmel. The results showed that, using the TMP36 for temperature compensation improves the accuracy of the designed system.***

Index Terms**:** ***Distance measurement, embedded system, microcontroller, temperature sensor, ultrasonic sensor.***

I. INTRODUCTION

Various techniques have been developed for non-contact distance measurements, whereas each way has their own advantages and disadvantages. Optical or infrared sensors offer good resolution but a poor measurement range. On the other side microwave or laser based systems present the possibility of a wide range distance measurement with the disadvantage of a rather poor resolution [1][2][3][4].

Mainly, the use of ultrasonic sensors is the most reliable and inexpensive method for distance measurement, which is widely used in automobiles to detect distance for parking assistance, in mobile robots to detect the obstacles for guidance. Beside their scientific and medical applications, the sensor can be used as level sensors in tanks for water or liquid level measurements [2][3][5]. Ultrasonic sensors are even useful under poor lighting conditions or when there are many transparent objects such as windows or glass doorways, as this is where infrared or vision-based sensors fail to be used. The sensor operation uses the principle of echo location. Sonar sensors transmitter sends out a short pulse within a specific direction. When the pulse hits an object, it bounces back, after which the echo can be picked up by a receiver. Most ultrasonic sensors use a single transducer to both transmit sound pulses and receive the reflected echo, typically operating at frequencies between 40 kHz and 250 kHz [6].

Different types of ultrasonic sensors were used in the previous related works. In [3] an ultrasonic sensor is interfaced to a peripheral interface controller (PIC) microcontroller to measure distances up to 2.5 m at 25 C°. In [4], an AVR Atmega16a microcontroller based range finder using ultrasonic HC-SR04 module is used for distance measurement. The design of ultrasonic distance measurement system is presented in [5] based on S3C2410 microcontroller, the module of temperature compensation circuit has been added to hardware circuit to improve the precision. In [6] a Parallax ultrasonic sensor is mounted on a mobile robot Pro-Bot 128 to measure distances from 20 mm to 200 mm at 24.8 C°. In [7] two separate ultrasonic transmitter and receiver were interconnected to a P89C51RD2 Phillips microcontroller development kit to measure distance from 5 cm to 50 cm at a room temperature of 20 C°. A SPARTAN 3E field programmable gate array (FPGA) board is used with an ultrasonic sensor in [8] to detect obstacles with a distance from 20 cm to 100 cm at a room temperature.

The speed of sound in dry air depends on temperature [9][10]. The major drawback of the previous works is the lack of a temperature compensation circuit that is needed for accurate distance measurement. In this paper a cheap and popular HC-SR04 ultrasonic sensor is used. The sensor is interfaced to an ATmega328P AVR microcontroller to compute distance from $5\,cm$ to $400\,cm$. A temperature sensor TMP36 from Analog Devices is also interfaced to the microcontroller for measuring temperature of the environment and thereby computing the speed of the sound wave to obtain a more accurate distance measurement. The computed distance is displayed via a liquid crystal display (LCD). Finally the main components of the system were soldered on general purpose soldering boards to appear as an embedded system.

II. PROPOSED SYSTEM

The proposed distance measurement system is shown in Fig.1. The DC supply voltage is connected to a voltage regulator to deliver a constant voltage to the microcontroller and other components in the system. The temperature sensor is interfaced to the microcontroller to measure temperature in both degrees Celsius and Fahrenheit. The ultrasonic sensor is also connected to the microcontroller, to compute distance. The resulting computed temperature and distance are display via the LCD. In this system, two pushbuttons switches are planned to be used, which are interfaced to the digital input pins of the microcontroller. The first switch, named Reset, is directly connected to reset pin of the microcontroller. When the Reset switch is pressed, the operation of the microcontroller will begin from the start. The second switch, named Mode, is used to measure temperature and calculate distance by pressing it.

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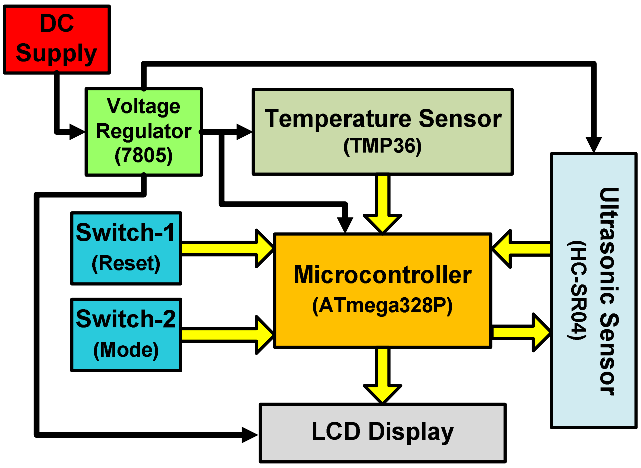

Fig.1: Proposed distance measurement system

A. Temperature Sensor

A temperature sensor is a sensor used to measure ambient temperature. These sensors use a solid-state technique to determine the temperature. In this work TMP36 is used, which is a rather complicated integrated circuit (IC), hidden in a package, as shown in Fig.2. It has three pins; the first pin is the supply voltage (V_{cc}), the second pin is the output voltage (V_G), which generates voltage that depends on temperature of the medium, and the third pin is ground (GND) [11].

Fig.2: Temperature sensor TMP36

The TMP36 provides a voltage output that is linearly proportional to the Celsius (centigrade) temperature, and it can read from −40°C to +125°C. The sensor outputs 10 mV per degree centigrade with a 500 mV offset on the output voltage pin. The following formula relates the generated voltage and temperature [11]:

$$V_G = (0.01 * T_C) + 0.5 \quad (1)$$

Therefore,

$$T_C = 100\,(V_G - 0.5) \quad (2)$$

Where, V_G is the generated voltage in volts, and T_C is temperature in degrees Celsius. To measure temperature in degrees Fahrenheit the following formula is used [11]:

$$T_F = (T_C * 1.8) + 32 \quad (3)$$

Where T_F is temperature in degrees Fahrenheit.

B. Ultrasonic Sensor

Ultrasonic sensors work based on the similar principle related to radar or sonar which evaluates the attributes of a target by interpreting the echoes from radio or sound waves, respectively. These sensors have a piezoelectric transducer (transmitter) which vibrates at ultrasonic or ultrasound frequencies. These pulses are emitted in a cone-shaped beam and aimed at a target object. The transmitted pulses are reflected by the object to the same or another transducer (receiver) of the sensor. The received pulses are detected as echoes [2][10][12]. Fig.3 illustrates the basic operation of ultrasonic sensors.

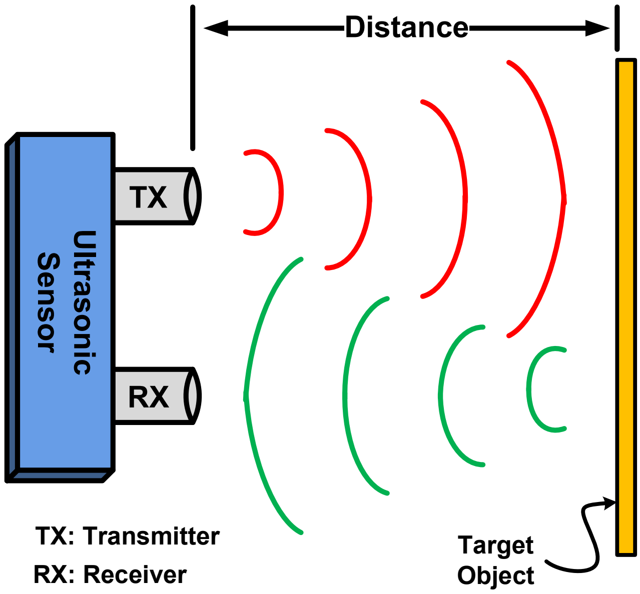

Fig.3: Basic operation of ultrasonic sensors

For distance measurement, usually the time-of-flight (TOF) method is used. In this case, the distance can be computed easily by knowing the speed of sound in the medium and time delay of the transmitted and reflected pulses. The equation for distance measurement is [2][9]:

$$L = \frac{1}{2}ct \quad (4)$$

Where L the distance between the sensor and target surface in meters, c is the ultrasonic speed in the medium measured in meters/second, and t is the flight time of the ultrasonic pulse in second. The speed of the ultrasonic wave depends on the type of the medium and temperature. In air the speed is given by [9]:

$$c = 331.45 + 0.6067\,T_c \quad (5)$$

Where T_c is temperature in degrees centigrade.

In this work, the popular HC-SR04 ultrasonic distance sensor is used to measure the distance of an object ranging from 2 centimeters to around 5 meters. The Sensor has a 4-pin header; it has a V_{cc} pin (it needs a 5V power supply), a trigger pin, an echo pin, and a ground pin, as shown in Fig.4.

Fig.4: The HC-SR04 ultrasonic sensor

A short 10μs pulse must be supplied to the trigger pin of the ultrasonic sensor to start the ranging, and the module will

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send out (transmit) an 8 cycle burst of ultrasound pulse at around 40 KHz. It then waits and listens for the pulse to echo back to the echo pin, and calculates the time taken to receive the pulse (echo) in microseconds [10].

At $T_C = 15$ ℃, the speed of sound is about $c = 340\ m/s$, therefore at this case the distance can be calculated based on equation (4) as follows:

$$
\begin{aligned}
L &= \frac{1}{2}.\left(340\frac{m}{s}\right).t \\
&= \frac{1}{2}.\left(340 \times \frac{100\ cm}{10^6 \mu s}\right).t \qquad (6) \\
&= \frac{t}{58.8236}
\end{aligned}
$$

C. Microcontroller

Microcontroller is the heart of an embedded system [12]. A microcontroller is a microcomputer that contains most of its peripheral devices and required memory inside a single integrated circuit along with the central processing unit (CPU) [13]. The ATmega328P microcontroller used in this work is an 8-bit AVR reduced instruction set computing (RISC) from Atmel [11]. In general, the Atmel AVR microcontrollers are very easy to use and can be run perfectly well by simply plugging them into a prototype board, adding a crystal oscillator, along with two capacitors, and connecting for programming. They are, coupled with the development of the AVR RISC core architecture that provides for very low-cost yet amazing solutions, and designed to run very fast through the use of a reduced number of machine-level instructions [13].

A typical ATmega328P microcontroller in a dual in-line package (DIP) is shown in Fig.5. The heart of the microcontroller is an 8-bit AVR CPU. The device has 2 kilo bytes (KB) of random access memory (RAM), 32 KB of programmable flash memory, and 1 KB of electrically erasable programmable read only memory (EEPROM). The microcontroller also has 14 digital I/O ports and 6 analog or ADC input ports. These ports link the microcontroller to the rest of electronic devices [11].

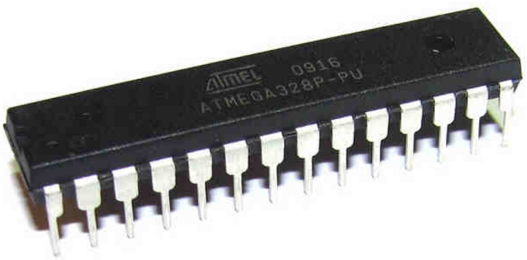

Fig.5: ATmega328P microcontroller in a typical DIP

The microcontroller has 28 pins. Pin 1 can be used to restart the execution of the microcontroller's program ($\overline{\text{RESET}}$), pin 7 is the supply voltage (V_{cc}), pin 8 and pin 22 are both ground (GND), pin 20 is a separate supply voltage for the ADC pins (AV_{cc}), and pin 21 is the reference voltage for the analog-to-digital converter (ADC) pins (AREF). Pins 9 and 10 are the crystal connection pins. An external 16 MHz crystal oscillator is needed to be connected to these pins. Pins 23 through 28 are ADC pins with 10-bit resolutions (A_0, A_1, A_2, A_3, A_4, and A_5). The rest of the pins are all general-purpose I/O pins ($D_0, D_1, D_2, \dots, D_{13}$) [11].

D. Liquid Crystal Display (LCD)

LCDs are commonly used display devices that have applications in the most appliances and electronic devices. By far the most simplest and popular LCD is the text panel based on the Hitachi HD44780U chip, as shown in Fig.6. This type of LCD can display 2 lines with 16 characters each. Every character consists of 5x8 or 5x11 dot matrix. In this paper, the LCD is used with a snazzy blue background with white characters [14].

Fig.6: The (16x2) HD44780 LCD display

The display has16 pins in a single row. To get the display working, the power, data, and control pins must be wired carefully. The function and description of each pin is demonstrated in Table. I. There are two basic ways to interface the device: 8-bit mode and 4-bit mode. Most often, the Read/Write (R/W) pin is just tied to ground, and the LCD is only written to and not read [14].

Table. I: Pin **description of the HD44780 LCD**

Pin NO.	Name	Function
1	GND	Ground (0V)
2	Vcc	Power (+5 V)
3	Vo	Contrast Voltage (usually less than 1V,this pin needs to be connected through a potentiometer for controlling the brightness of the display backlight)
4	RS	Register Select (logic 1 for data write, 0 for command write)
5	R/W	Read/Write (1 for data read from the LCD register, 0 for data write to the register)
6	EN	Enable line [to send data to the LCD, put data on the data bus, then make EN high (1) and wait a little bit and end by bringing EN to low (0) again]
7-14	D0-D7	Data bus lines (D0 is LSB, in 4-bit mode only D4-D7 are used)
15	LED+	Power for backlight (+4.3V)
16	LED-	Backlight ground (0V)

E. Voltage Regulator

A voltage regulator provides a constant DC output voltage that is not affected by the input voltage, output load current, and temperature. In this work, a common 7805 integrated circuit (IC) regulator is used that provides a fixed positive 5 V output voltage [15]. The regulator has three terminals, which are input, ground, and output as shown in Fig.7.

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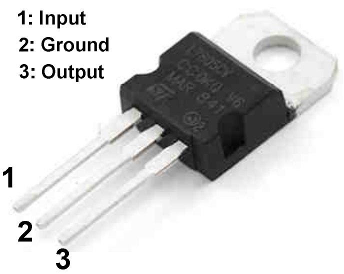

Fig.7: The 7805 Voltage Regulator package

Capacitors are sometimes used on the input and output of the regulator. The input capacitor prevents unwanted oscillations when the regulator is some distance from the power supply filter. The output capacitor acts basically as a line filter to improve transient response. Almost all applications of regulators require that the device be secured to a heat sink to prevent thermal overload [15].

III. DESIGN AND IMPLEMENTATION

The design of the embedded distance measurement system is shown in the schematic diagram of Fig.8. As it can be seen a 16 MHz crystal oscillator (XTAL), along with the two capacitors C_1 and C_2 is connected. Therefore, the microcontroller ticks 16 million times per a second and on each of those ticks, the device can perform one mathematical operation. In this system, two pushbutton switches are used, the first one is S_1 and named Reset which is connected to reset pin of the microcontroller through a pull-up resistor. The other switch is S_2 and named Mode, which is connected to digital pin D_9 of the microcontroller through a pull-up resistor and used to measure temperature and calculate distance.

The microcontroller is programmed using a processing based language similar to C++. The flowchart for programming the microcontroller is shown in Fig.9.

Pressing the Mode switch each time a different mode will be displayed on the LCD screen among three modes. Therefore, there are three different modes to be displayed on the LCD by pushing the Mode switch; the first mode will show temperature in both degrees Celsius and Fahrenheit, based on the equations (2) and (3), respectively. The second mode will calculate distance based on equation (6), and the third mode will calculate distance (more accurate) based on equations (4) and (5). The second mode uses only the ultrasonic sensor to calculated distance (without temperature compensation); in this case it is assumed that the speed of sound is to be $c = 340\ m/s$ at temperature $T_c = 15$. The third mode uses the temperature sensor (with temperature compensation) to calculate the speed of the ultrasonic wave, and then the distance is calculated. The latter case will give more accurate distance measurement because changing temperature of the medium will change the speed of sound, and thereby affects the accuracy of the distance measurement. The complete design of the system is shown in Fig.10; where the design elements were soldered on soldering boards and inserted into a general purpose box.

The comparison of the true and computed distances is shown in Fig. 11. The measurements are taken in two separate temperatures ($5\ ℃°$ and $35\ ℃$). As it is evident from the results, using the temperature sensor in the third mode of the designed system improves the accuracy of the distance measurements compared to the second mode.

IV. CONCLUSION

In this work an embedded system is designed and successfully implemented using an ATmega328P microcontroller from Atmel. The system can be used to measure distance of objects ranging from $2cm$ to $400\ cm$, using a cheap HC-SR0 ultrasonic distance sensor. For improving the accuracy of the measurement a TMP36 sensor is used for temperature compensation, since the speed of ultrasonic waves will be affected by temperature changes. As it is clear from the results, using the TMP36 sensor for temperature compensation increases the accuracy of the designed system and reduces error in the distance measurements.

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REFERENCES

[1] Hannes Elmer, and Herbert Schweinzer, “High Resolution Ultrasonic Distance Measurement in Air Using Coded Signals”, IEEE Instrumentation and Measurement Technology Conference, pp.(1565-1570), Anchorage, AK, USA, 2002.

[2] R. Raišutis, O. Tumšys, and R. Kažys, “Feasibility study of application of ultrasonic method for precise measurement of the long distances in air”, ULTRAGARSAS journal, pp. (7-10), Vol. 65, No. 1, 2010.

[3] Md. Shamsul Arefin, and Tajrian Mollick, “Design of an Ultrasonic Distance Meter”, International Journal of Scientific & Engineering Research, pp. (1-10), Vol.4, Issue-3, 2013.

[4] Rajan P Thomas, Jithin K. K., Hareesh K. S., Habeeburahman C. A., and Jithin Abraham, “Range Detection based on Ultrasonic Principle”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, pp. (7638-7642), Vol. 3, Issue 2, February 2014.

[5] Hongjiang He, and Jianyi Liu, “The Design of Ultrasonic Distance Measurement System Based on S3C2410”, IEEE International Conference on Intelligent Computation Technology and Automation, pp. (44-47), 2008.

[6] Radu TARULESCU, “Usage of Parallax Ultrasonic Sensors in Distance Measurements”, ANNALS OF THE ORADEA UNIVERSITY Journal, Fascicle of Management and Technological Engineering, pp.(393-396), Vol. XXII (XII), 2013/1, ISSUE-1, 2013.

[7] A. K. Shrivastava, A. Verma, and S. P. Singh, “Distance Measurement of an Object or Obstacle by Ultrasound Sensors using P89C51RD2”, International Journal of Computer Theory and Engineering, pp. (64-68), Vol. 2, No. 1 2010.

[8] K. Srilakshmi, K. Anitha, P. Rajesh Kumar, and G.R.L.V.N. Srinivas Raju, “Design and Implementation of Distance Measuring Digital Hardware”, International Journal of Electronics & Communication Technology (IJECT), pp. (222-225) Vol. 2, SP-1, Dec . 2011.

[9] Jie Liang and Zhiguang Guan, “Design of Intelligent Automatic Leveling Control System Based on Ultrasonic Distance Measuring Technology”, Proceedings of the IEEE International Conference on Automation and Logistics, pp. (1620-1624), Jinan, China, 2007.

[10] Vigneshwari C., Vimala V., and Sumithra G., “Sensor Based Assistance System for Visually Impaired”, International Journal of Engineering Trends and Technology (IJETT), pp. (4338-4343), Vol. 4 Issue-10, 2013.

[11] Jeremy Blum, "Exploring arduino", 1st edition, John Wiley & Sons Inc., Indiana, USA, 2013.

[12] Sai Prabha M., Roy K. S.,Shaik Mahaboob Ali, “Obstacle Avoidance With Anti Theft Mechanism System And Cabin Safety System For Automobiles”, pp. (1264-1268), International Journal of Engineering Trends and Technology (IJETT), Vol. 4, Issue-4, 2013.

[13] Richard Barnett, Larry O’Cull, and Sarah Cox ,Embedded C Programming and the Atmel AVR, 2nd edition, Delmar, Cengage Learning, USA, 2007.

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[14] Simon Monk, "Programming arduino", 1st edition, McGraw-Hill, USA, 2012.
[15] Thomas L. Floyd, "Electronic devices conventional current version", 9th edition, Prentice Hall, New Jersey, USA, 2012.

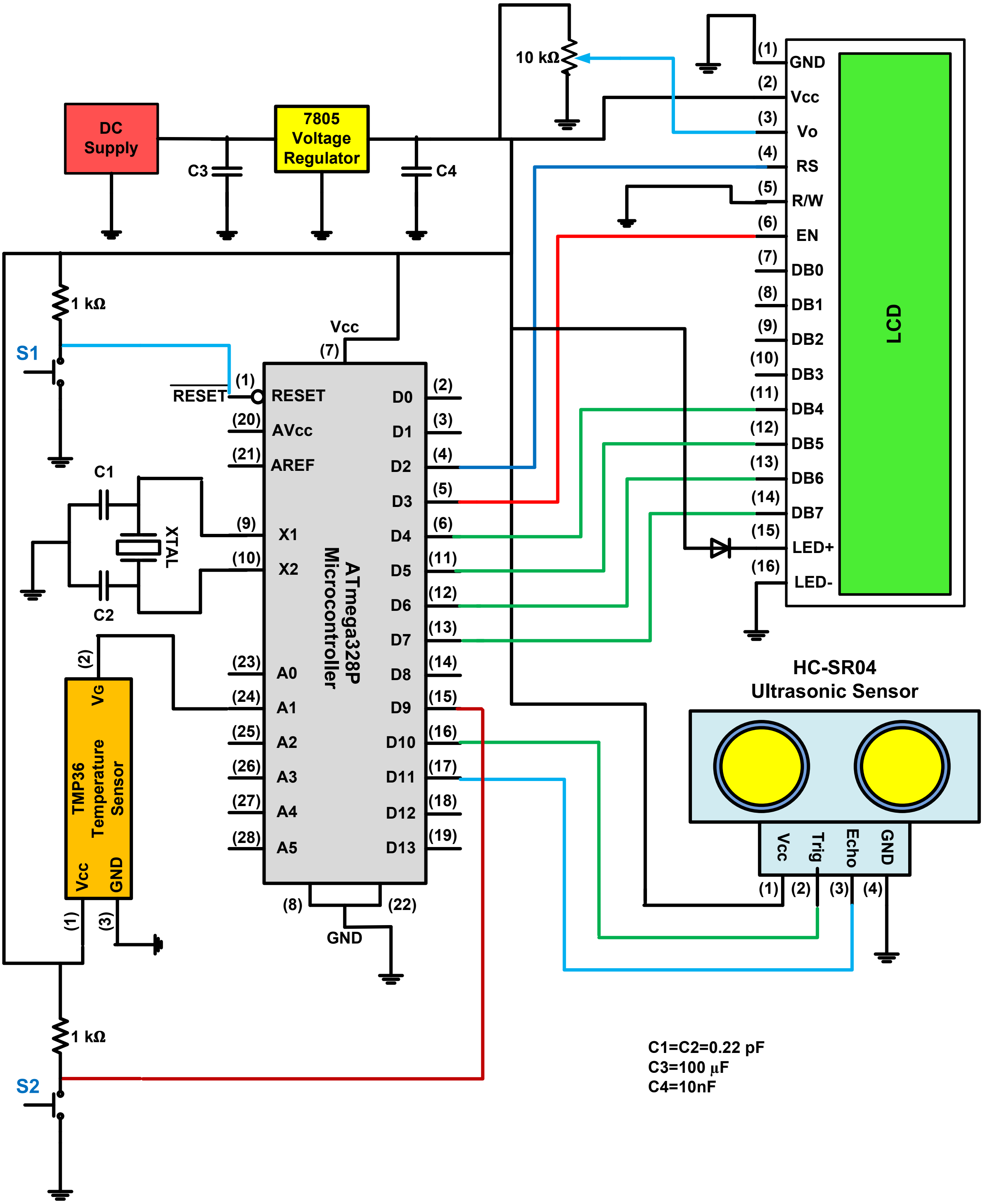

Fig.8: Schematic diagram of the embedded distance measurement system

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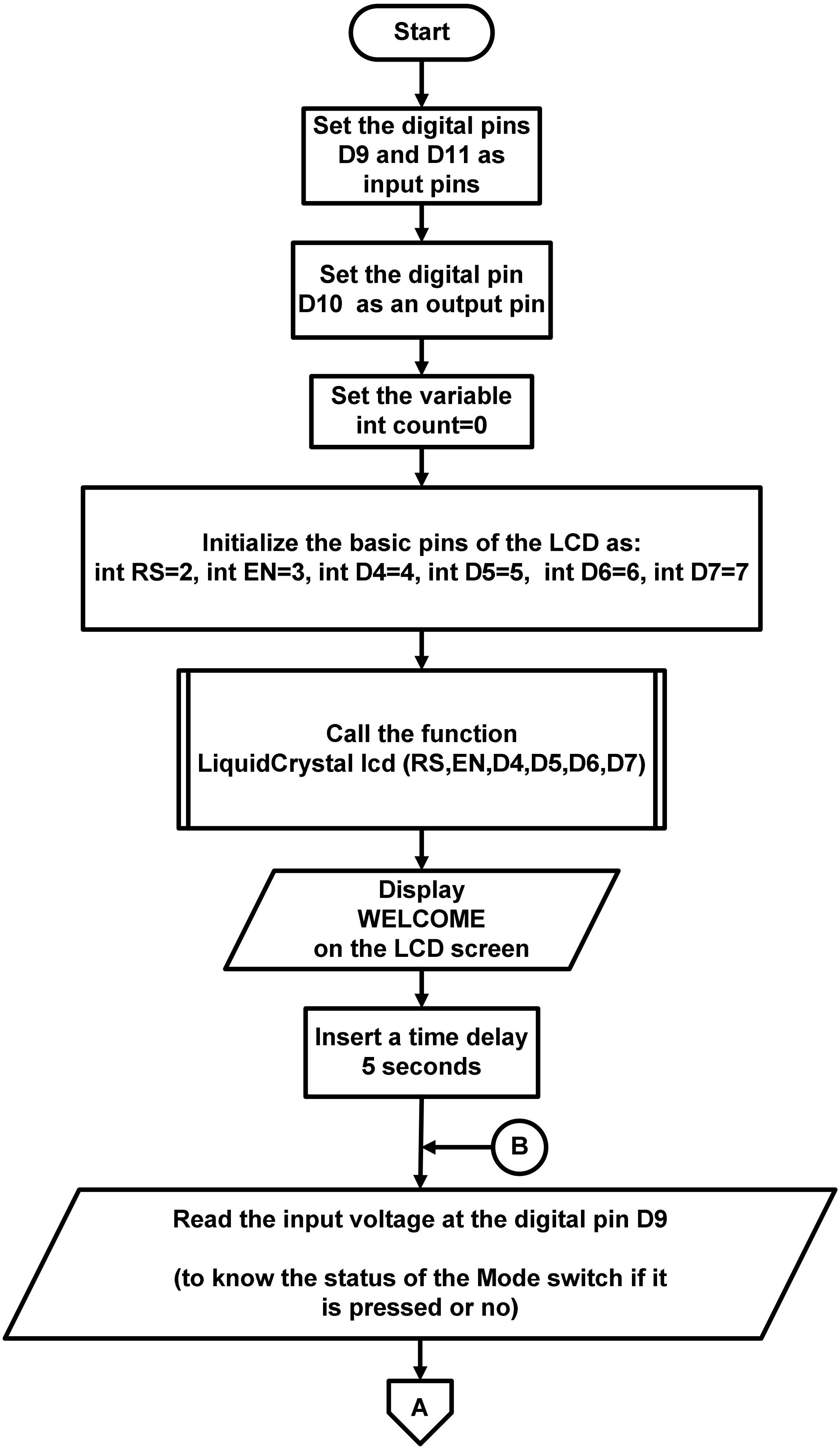

Fig.9: Flowchart for programming the microcontroller

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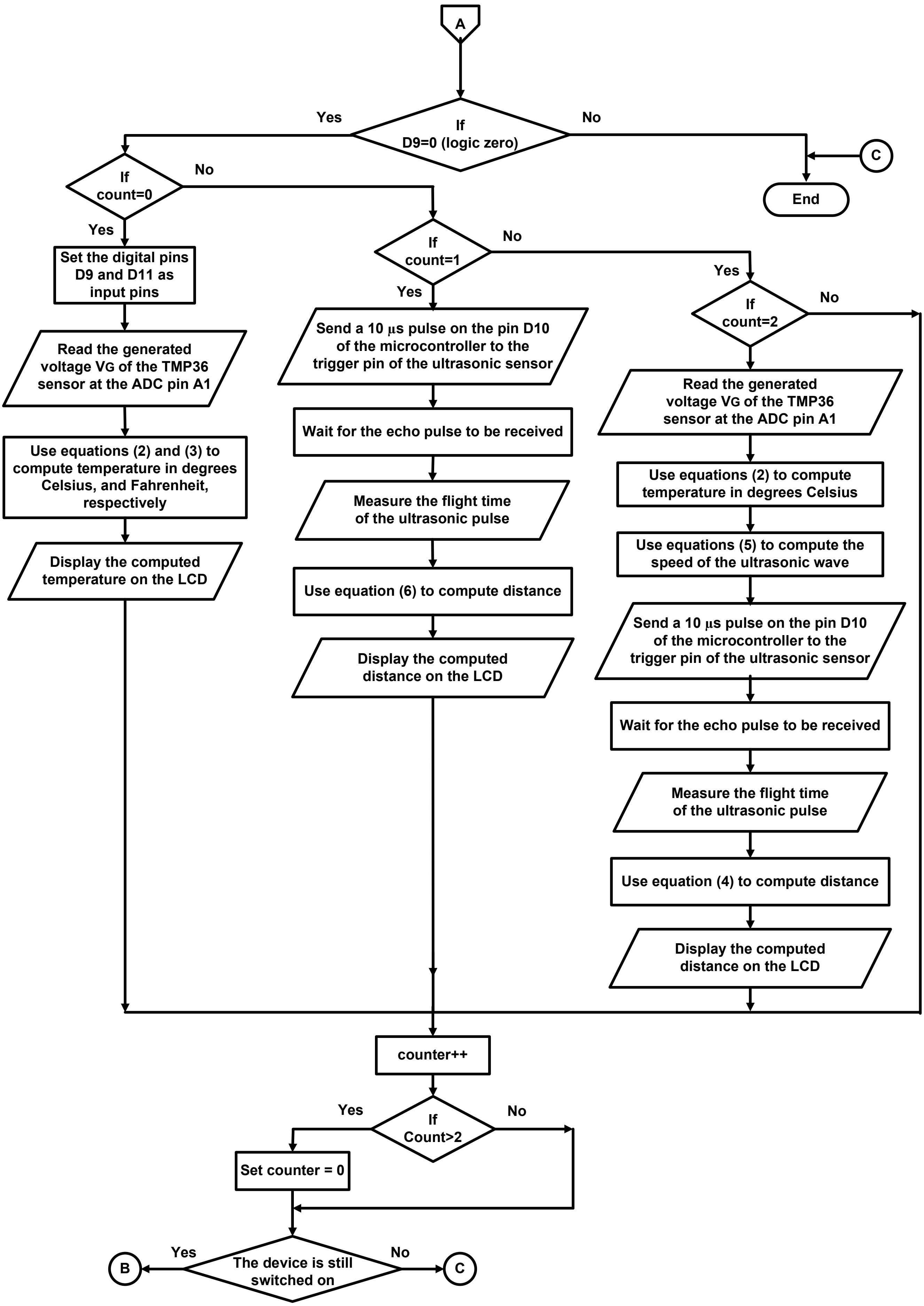

Fig.9: (continued)

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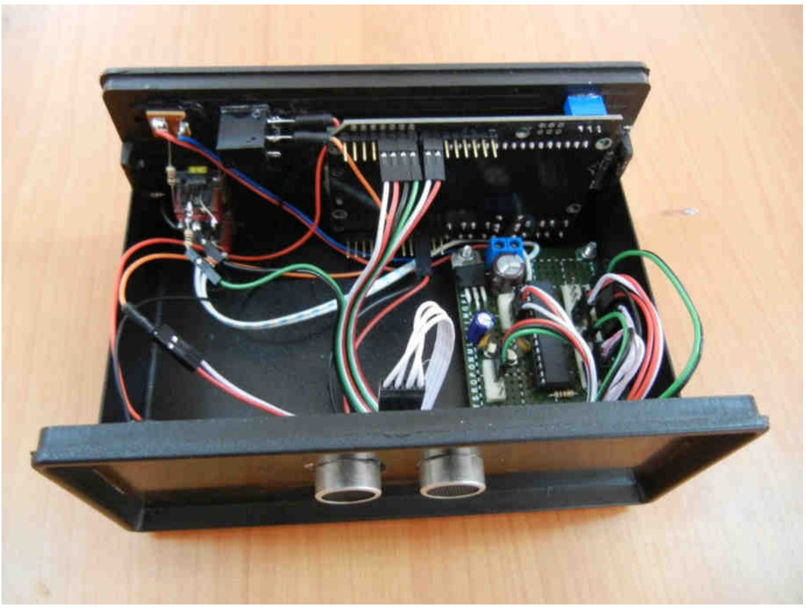
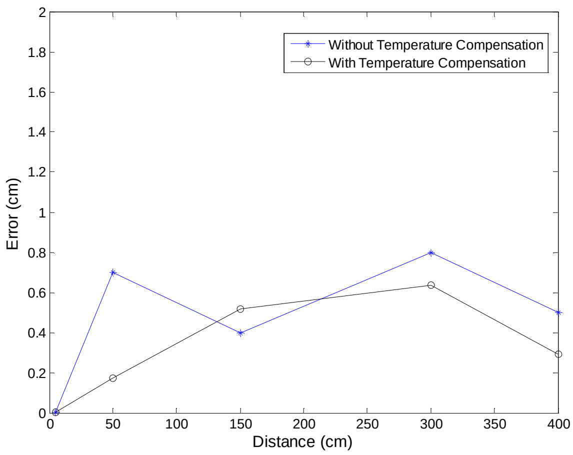
(a) **Front view**

(b) **Back view**

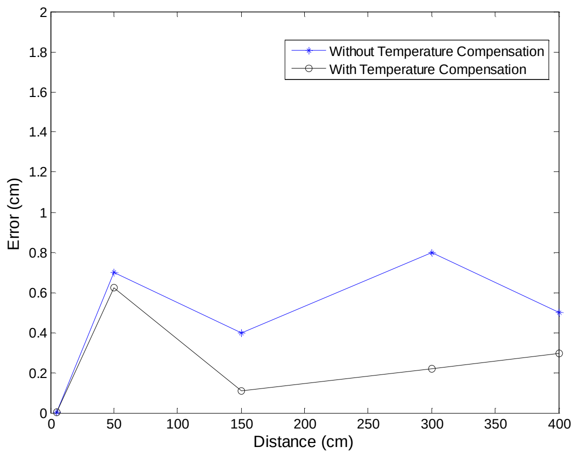


(c) **Internal view**

Fig.10: The complete design of the embedded system



(a) At $T_C = 5$ ℃



(b) At $T_C = 35$ ℃

Fig.11: Absolute errors of the computed distances