Development of Device for the Estimation of Ambient Temperature by measuring Ultrasonic Propagation Velocity in Air

International Conference On Ultrasonics And Material Science For Advanced Technology (ICUMSAT-2025)

Saransh*, Nitin Dhiman and P. K. Dubey

Department of Electronics Engineering, J.C. Bose University of Science and Technology, YMCA Faridabad-121006, India

Pressure, Vacuum and Ultrasonic Metrology, Division of Physico-Mechanical Metrology,

CSIR-National Physical Laboratory, Dr. K. S. Krishnan Marg, New Delhi-110012, India

Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India

*Email: saransh.vas@gmail.com

Introduction

What is an Ultrasound ?

- **You can't hear it** – ultrasound has a frequency above 20 kHz, beyond the human hearing range of 20 Hz–20 kHz.
- **It needs a medium to travel** – ultrasound moves through air, liquids, or solids as mechanical waves.
- **It reflects back from objects** – this echo behavior makes ultrasound useful for sensing, measurement, and imaging.

1. Longitudinal or Compression Waves
2. Transverse or Shear Waves

Generation:

- Piezoelectric Method
- EMAT Methods

Applications:

- Calibration
- Research and Engineering
- Medical

Ultrasonic testing methods:

- Single transducer method (Pulse-echo method)
- Two transducer method (Through transmission method)

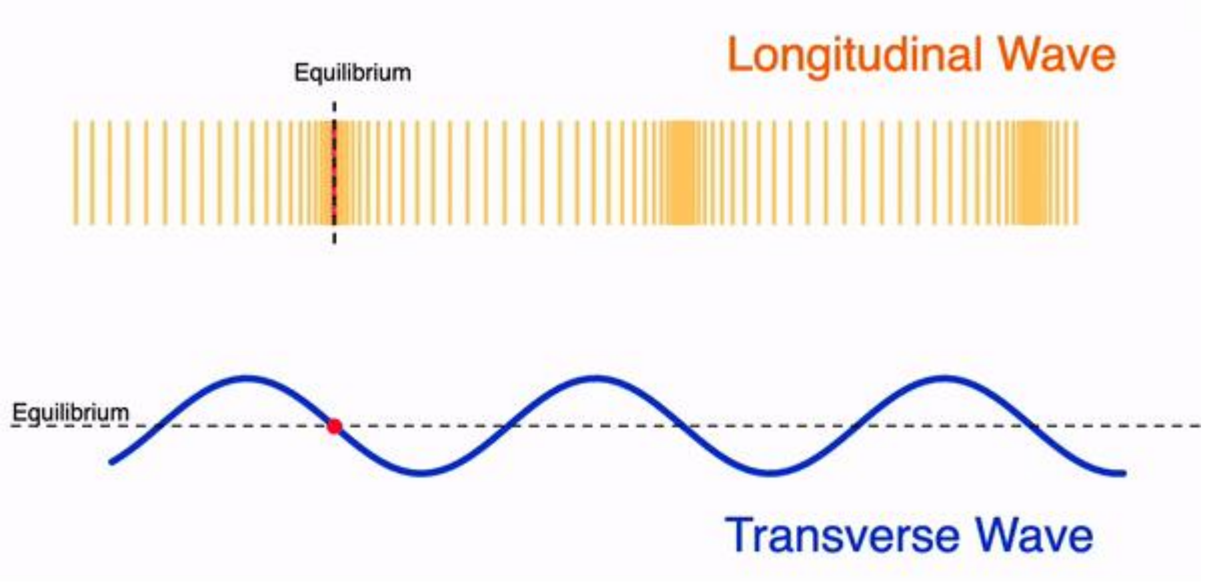

Fig.1 Propagation of waves

Ultrasonic Technique for Temperature Measurement:

- Time-of-Flight Method
- ✓ Measures the travel time of ultrasonic pulses between transducer and reflector
- ✓ Converts measured time into sound velocity to estimate temperature

Temperature Measurement using Ultrasonic Propagation Velocity

Working principle:

The principle used in the measurement of ambient temperature is based on the accurate determination of the ultrasonic velocity in air. The temperature *T* can be calculated by the following equation:

$$T = \frac{c - 331.4}{0.606} \qquad (1)$$

where, c is the velocity of sound in air in m/s, ***331.4*** m/s is the velocity of sound at 0°C, ***0.606*** is the temperature coefficient, indicating how sound speed increases per degree rise in temperature, T is the ambient temperature in °C.

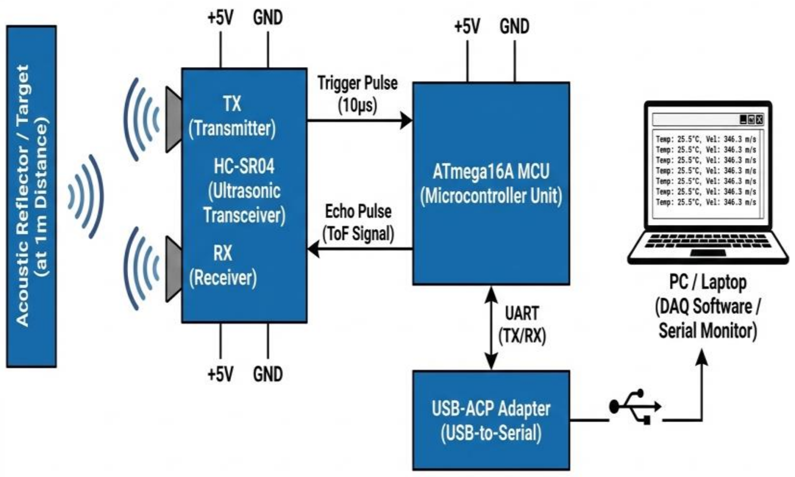

Fig.2 Systematic diagram

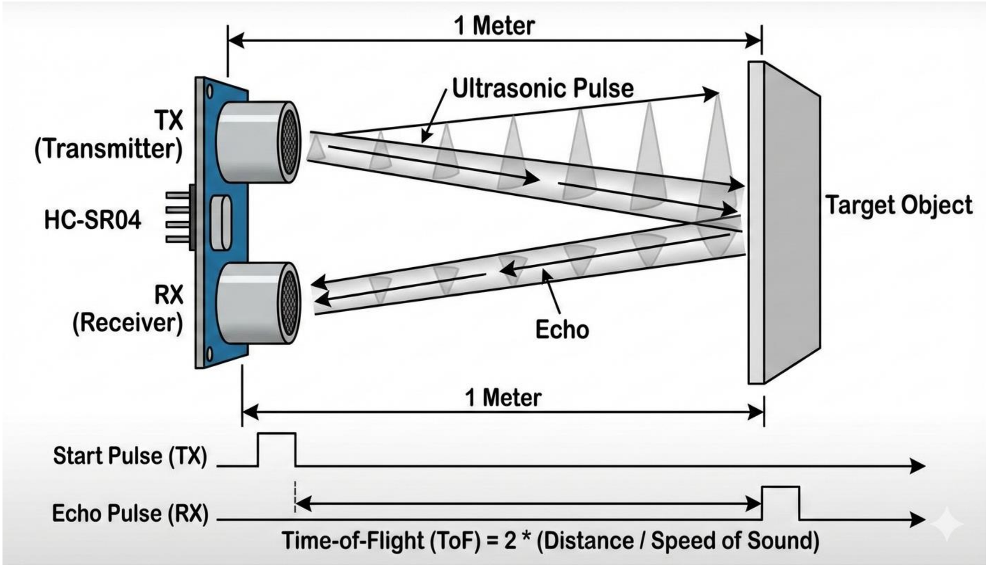

Fig.3 Representation of system

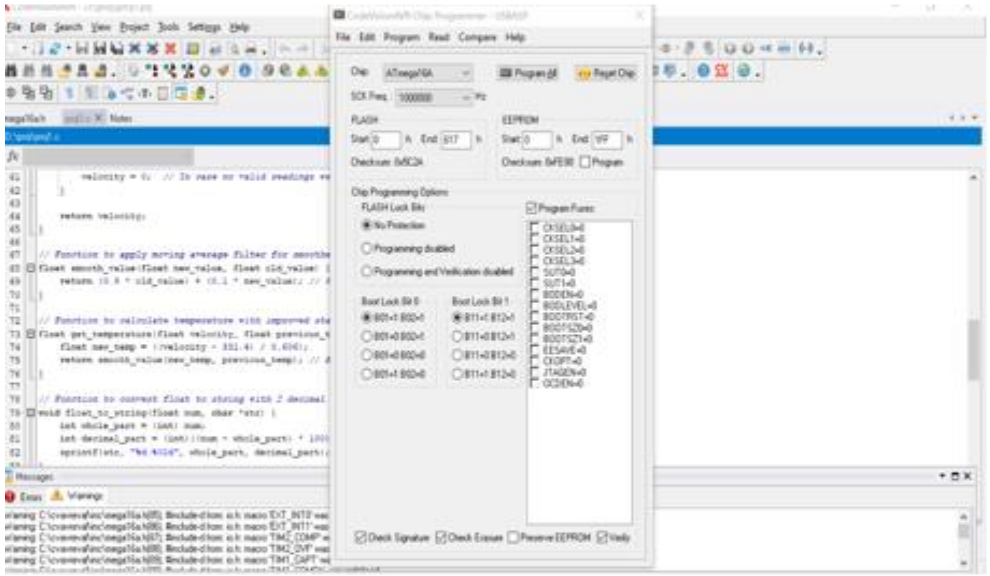

Fig.4 Software of ultrasonic system

Relationship between Velocity and Temperature

The ultrasonic pulse is emitted from the transducer and reflected back from a fixed reflector. The round-trip time of the pulse is measured digitally to determine the velocity of sound in air is given by [1,5,11]:

$$c = \frac{2d}{t} \quad (2)$$

In this equation, **c** represents the velocity of sound in air in m/s, **d** is the distance between the sensor and the reflector in m, and **t** is the measured round-trip time of flight in sec.

The velocity of sound in air depends on the ambient temperature, which is described by the equation is given by [4]:

$$c = 331.4 + 0.606\,T \quad (3)$$

Here, **T** is the ambient air temperature in °C.

Rearranging this equation gives the final expression for temperature:

$$T = \frac{c - 331.4}{0.606} = \frac{\frac{2d}{t} - 331.4}{0.606} \quad \text{(Substituting 2 in 3)}$$

This final equation directly relates the measured time of flight to the ambient temperature, forming the core principle of the device.

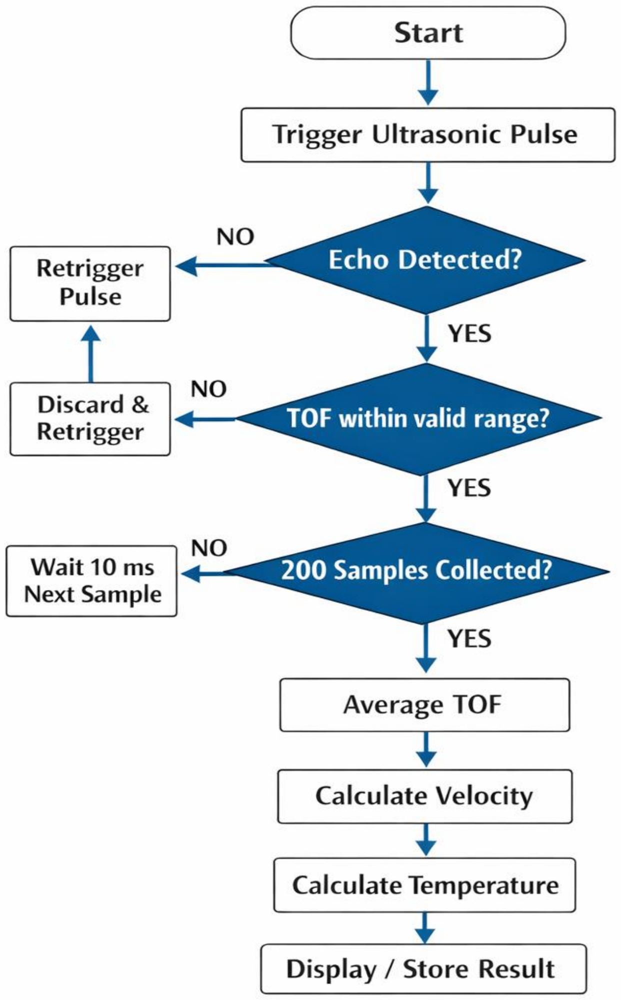

Fig.5 Flowchart

Features, Advantages and Factors Affecting Ultrasonic Velocity

- **Features:** There are many features of ultrasonic temperature measurement. Some of them are:

➢ Real-Time Calculation.

➢ Automated Ultrasonic Triggering

➢ Multi-Sample Averaging

- **Advantages:**

➢ High Accuracy

➢ Easy Integration

➢ Low Cost

- **Factors which affect the ultrasonic velocity:**

➢ Pressure & Humidity

➢ Scattering & Diffraction

➢ Frequency

➢ Attenuation

Fig.6 Factors Affecting Ultrasonic Velocity

Results

➤ **Change in Temperature w.r.t. Velocity**

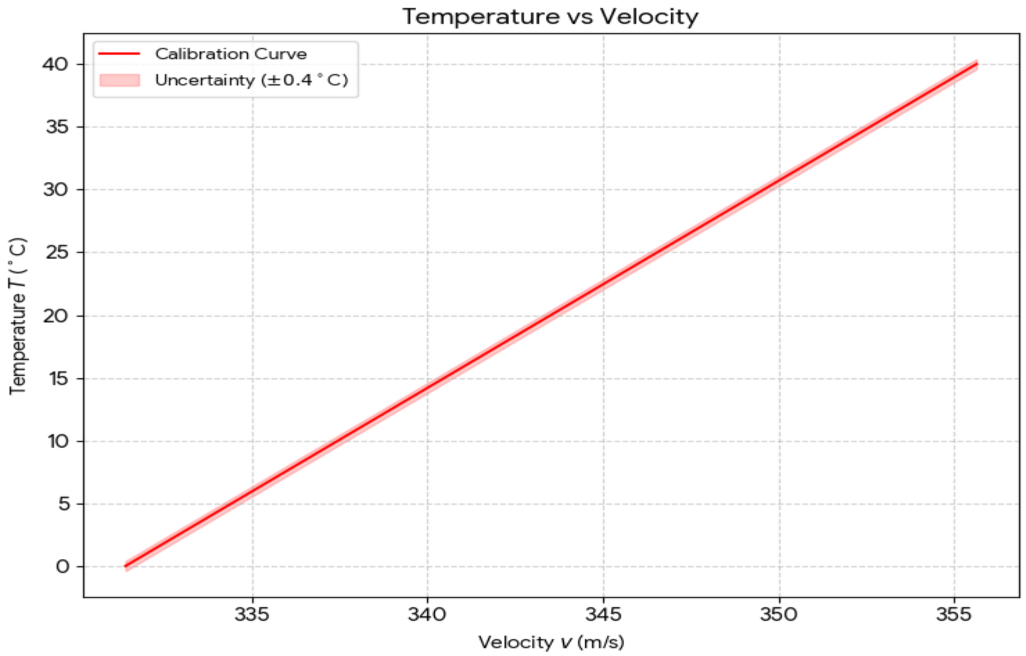

Fig.7 Graph of measured velocity vs calculated temperature

➤ **Total Counts w.r.t. Temperature**

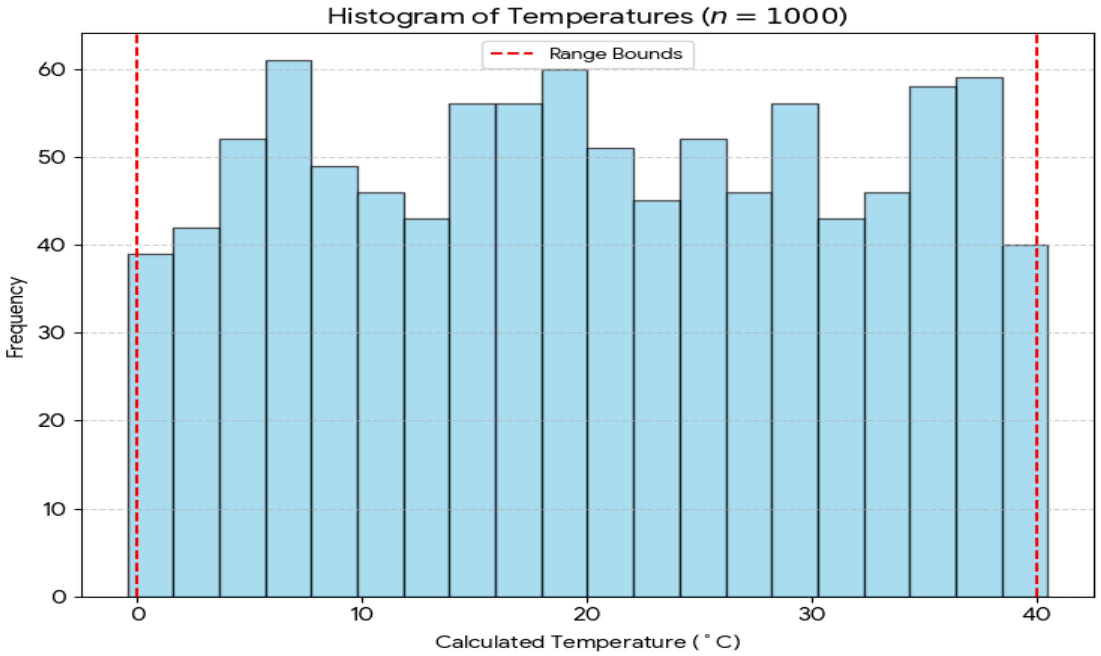

Fig.8 Statistical Frequency vs calculated temperature

Temperature (T) [∘C]	Velocity (v) [m/s]	Statistical Frequency (Counts)	Uncertainty in T [∘C]
15	340.49	56	±0.4
20	343.52	60	±0.4
25	346.55	52	±0.4
30	349.58	56	±0.4
35	352.61	58	±0.4

Conclusion

- **High-Precision Temperature Estimation:** The system successfully measured ambient temperature by calculating ultrasonic propagation velocity with a ±0.4 °C uncertainty.
- **Effective Signal Processing:** Implementing 200-sample averaging and timing synchronization minimized errors due to environmental noise and sensor fluctuations.
- **Robust Embedded Implementation:** The ATmega16A-based prototype with HC-SR04 and acoustic reflector provided a stable, repeatable setup for real-time measurements.
- **Practical Applicability:** The method demonstrates a non-contact, low-cost, and reliable technique for ambient temperature estimation, suitable for laboratory and industrial settings.
- **Foundation for Future Innovations:** The project establishes a framework for advanced ultrasonic sensing applications, including assistive technology, environmental monitoring, and precision instrumentation.
- **Real-World Impact:** This approach can enhance temperature monitoring in sensitive environments (labs, industrial setups, or clinical settings), reducing manual errors and improving safety and efficiency.

References

[1]. Waveshare Electronics, *HC-SR04 Ultrasonic Module Datasheet*, 2021. Available: https://www.waveshare.com/wiki/HC-SR04

[2]. Microchip Technology Inc., *ATmega16A Microcontroller Datasheet*, 2018. Available: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-2549-8-bit-AVR-ATmega16A_Datasheet.pdf

[3]. Kinsler, L. E., Frey, A. R., Coppens, A. B., & Sanders, J. V., *Fundamentals of Acoustics*, 4th Edition, Wiley, 2000.

[4]. Cramer, O., *Temperature Dependence of the Speed of Sound in Air*, Journal of the Acoustical Society of America, 1993.

[5]. Rahman, A., *Precision Distance Measurement Using Ultrasonic Sensors*, International Journal of Engineering Research, 2018.

[6]. Banzi, M., *Getting Started with Arduino*, 3rd Edition, O'Reilly, 2014.

[7]. Regehr, J., *Embedded C Programming and the Atmel AVR*, 2nd Edition, 2019.

[8]. Patel, R., *Calibration of Ultrasonic Distance Sensors for Precision Measurement*, Measurement Science Review, 2017.

[9]. Smith, S. W., *The Scientist and Engineer's Guide to Digital Signal Processing*, 2nd Edition, 1997.

[10]. Ahn, J., et al., *Non-Contact Temperature Measurement Using Ultrasonic Propagation Velocity*, Sensors and Actuators A, 2015.

[11]. Waveshare Tech Note: *HC-SR04 Timing*, 2020. Available: https://www.waveshare.com/wiki/HC-SR04#Timing

[12]. Jones, R., *PCB Design for Real-Time Embedded Systems*, 1st Edition, Elsevier, 2016.

[13]. Eggers, F., & Funck, T., *Ultrasonic Distance Measurement Techniques*, Review of Scientific Instruments, 44 (1973), pp. 969–977.


Thank
you