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APPLICATION AND ANALYSIS OF ULTRASONIC SENSORS FOR RIVER LEVEL MEASUREMENT

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Abstract
This study presents the development and experimental testing of an innovative technology for measuring river levels, aimed at achieving accuracy comparable to that of high-cost radar systems. The solution utilizes the MB7076 XL ultrasonic sensor from the MaxSonar-WRLA1 series, combined with intelligent software analysis of the analog signal and the application of various temperature compensation approaches. The system was tested under real conditions on the Yantra River in Gabrovo, Bulgaria, with adjustments implemented to minimize measurement error. The results demonstrate that, with appropriate temperature correction and advanced signal analysis algorithms, an error of less than 3% can be achieved, and under optimized conditions – as low as 0.5%. The system provides a reliable and affordable alternative for hydrological monitoring and intelligent infrastructure within the context of sustainable water resource management and Smart Cities.
Keywords: ultrasonic, senson, inovative, technology, sustainable, water, management.

INTRODUCTION

Monitoring water levels in rivers, reservoirs, and other open water bodies is a key component in natural resource management, flood forecasting, hydroelectric power generation, and environmental research. Existing water level measurement systems typically rely on high-precision radar or laser sensors, which, however, are significantly expensive, require periodic maintenance, and often depend on well-developed communication and power infrastructure. This limits their applicability in areas with limited resources or in locations where building traditional stations is economically inefficient.

With the advancement of microcontroller technologies, ultrasonic sensors, and cloud-based data platforms, new opportunities have emerged for developing low-cost, autonomous, and intelligently connected systems. Ultrasonic sensors measure the distance to a surface by determining the Time-of-Flight (ToF) of a sound wave traveling through the air and are characterized by low power consumption, high reliability, and the absence of mechanical components. Their main limitation lies in the dependency of the speed of sound on ambient temperature, and to a lesser extent on humidity and air pressure. This dependency necessitates the application of temperature compensation to ensure measurement accuracy.

Ultrasonic measurement of water levels is based on the principle of time-of-flight (ToF), in which the sensor emits high-frequency sound waves (above 20 kHz) that are reflected from the water surface and return to the receiver. By measuring the time between transmission and reception of the echo, the system calculates the distance using the known speed of sound in air. According to *Ultrasonic Sensing Basics*

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(Rev. D) by Texas Instruments [1], ultrasonic sensors are piezoelectric transducers that convert electrical signals into mechanical vibrations and vice versa, enabling non-contact distance measurement to solid or liquid surfaces. The speed of sound and the intensity of reflection depend on temperature, humidity, and the acoustic impedance of the medium, making temperature compensation and proper signal processing essential for accuracy. The technology is particularly suitable for hydrological monitoring, as it allows reliable measurement of water levels without direct contact with the liquid, while ensuring resistance to dust, rain, and environmental variations [1].

The monitoring of water levels in rivers, reservoirs, and other open water bodies is a key element in natural resource management, flood forecasting, hydroelectric energy production, and environmental research. Existing water level measurement systems typically rely on high-precision radar or laser sensors, which, however, are significantly expensive, require periodic maintenance, and often depend on well-developed communication and power infrastructure. This limits their application in areas with limited resources or in locations where building traditional stations is economically inefficient.

With the development of microcontroller technologies, ultrasonic sensors, and cloud data platforms, new opportunities have emerged for the creation of low-cost, autonomous, and intelligently connected systems. The main limitation of ultrasonic sensors lies in the dependence of the speed of sound on ambient temperature, and to some extent, on humidity and air pressure. This dependency requires the application of temperature compensation to ensure measurement accuracy.

In recent years, many authors have explored the potential applications of ultrasonic sensors in hydrology and water engineering.

Masoudimoghaddam, Yazdi, and Shahsavandi (2025) developed a low-cost ultrasonic device for online monitoring of river levels with accuracy up to 1 mm, based on the GY-US42 sensor. The system includes temperature compensation using an LM35 sensor, averaging of multiple measurements, and stabilization through a 3D-printed funnel, reducing errors to below 3% even under field conditions. The authors emphasize that the low cost and integration with GSM/GPRS modules make the device suitable for large-scale deployment in hydrometric networks [2].

Mohammed et al. (2019) used a PING ultrasonic sensor and a PIC16F877A microcontroller for measuring water level and volume in tanks. The system achieved an error below 0.07 cm for level and below 0.065 L for volume, with high correlation coefficients (SCC = 0.9997, KCC = 0.9951). The authors noted that ultrasonic methods offer excellent accuracy at low cost and low energy consumption, making them suitable for both industrial and domestic applications [3].

Pereira, de Carvalho, Mendes, and Formiga (2022) analyzed the use of HC-SR04 ultrasonic sensors with an Arduino controller for measuring water levels in open channels. The study covered both laminar and turbulent flow regimes, finding that measurement errors increased with turbulence but remained within ±0.02 m—an acceptable range for hydraulic measurements. The authors concluded that the Arduino–HC-SR04 combination is both economically and technically effective, especially when sensors are well calibrated and signal filtering algorithms are applied [4].

Rocchi et al. (2019) discussed the development of intelligent IoT systems for hydrological monitoring that incorporate ultrasonic sensors and wireless communication. They emphasized that integrating inexpensive, autonomous devices can significantly improve the spatial coverage of monitoring networks while reducing operational costs and enhancing system resilience to extreme weather events [5].

These studies clearly indicate a trend toward the democratization of hydrometric technologies through open hardware and microcontroller platforms.

EXPOSITION

The present study aims to demonstrate a developed cloud-based system for measuring river depth using the ultrasonic sensor MB7076 XL from the MaxSonar-WRLA1 series (MaxBotix Inc.). The main concept is to achieve an accuracy comparable to that of industrial radar systems through intelligent signal processing and software algorithms for temperature correction, while maintaining minimal hardware costs. The project focuses on achieving a balance between accuracy, reliability, and affordability, resulting in an autonomous station capable of transmitting data in real time through cloud infrastructure.

The hardware configuration includes an ultrasonic sensor, microcontroller, temperature sensor, and communication module, all mounted in a protective enclosure with a solar radiation shield. This design minimizes the influence of direct sunlight on the measured temperature and provides a realistic assessment of the air temperature in the immediate vicinity of the sensor. Through this optimization, temperature compensation becomes more precise, and errors caused by local heating are reduced.

The software component of the system is based on an advanced algorithm for analog signal analysis that allows identification of the main echo while ignoring parasitic reflections from vegetation, branches, or other nearby objects. An additional parameter introduced in the algorithm is the Signal Quality Index (SQI), based on the number and amplitude of detected echoes. This metric improves data reliability and enables automatic filtering of invalid measurements.

Field tests conducted under real conditions on the Yantra River – at the Racho Kovacha monument and on a bridge in the Etara district—confirm that the system maintains stability and accuracy under different atmospheric and lighting conditions. Initial experiments showed deviations below 3% in sunny weather and up to 0.5% under laboratory conditions. The results demonstrate the potential of ultrasonic sensors as a cost-effective tool for hydrological monitoring.

In a broader context, the developed system fits into the concept of Smart Cities and sustainable water resource management. Integrating such networked devices into an intelligent ecosystem for data collection and analysis would enable: automated river level monitoring and early flood warning; climate trend analysis through the combination of temperature and hydrological data; energy-efficient and scalable infrastructure using renewable sources (e.g., solar power); remote management and diagnostics via Internet connectivity (IoT architecture).

Thus, the proposed system not only demonstrates the feasibility of a technological replacement for costly industrial solutions but also opens the perspective for creating national or regional networks of intelligent stations, connected through a cloud platform for monitoring and analyzing water resources. This makes it a significant contribution to the digitalization of environmental monitoring and to the concept of sustainable development within the framework of the Fourth Industrial Revolution (Industry 4.0).

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With the development of microcontroller technologies, ultrasonic sensors, and cloud data platforms, new opportunities have emerged for the creation of low-cost, autonomous, and intelligently connected systems.

The present project aims to develop a cloud-based system for measuring river depth using the ultrasonic sensor MB7076 XL-MaxSonar-WRLA1 from the MaxSonar-WR series by MaxBotix Inc. The main concept is to achieve accuracy comparable to industrial radar systems through intelligent signal processing and software algorithms for temperature correction, while maintaining minimal hardware costs. The project emphasizes achieving a balance between accuracy, reliability, and affordability, resulting in an autonomous station capable of transmitting data in real time through cloud infrastructure.

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Field tests conducted under real conditions on the Yantra River – near the Racho Kovacha monument and on a bridge in the Etara district – confirmed that the system maintains stability and accuracy under varying atmospheric and lighting conditions. Initial experiments showed deviations below 3% in sunny conditions and up to 0.5% in laboratory tests. The results demonstrate the potential of ultrasonic sensors as an economically efficient tool for hydrological monitoring.

Principle of Ultrasonic Distance Sensor MB7076 from the XL-MaxSonar-WRLA1 Series by MaxBotix Inc.: The sensor emits a single burst of ultrasonic pulses with a duration of approximately 1 ms and a frequency of 42 kHz, after which it switches to receiving mode and waits to detect the reflected signal. The transmitted and received signals are processed by the internal electronic circuitry to produce an amplitude envelope, which is output on a designated pin of the sensor's electrical connector. The connector also provides power supply pins, as well as a serial interface and other outputs — such as an analog voltage proportional to distance or a pulse with a duration proportional to distance, depending on the specific type of sensor selected from the MaxSonar series.

Oscillogram of the signal (Fig.1) across the entire measurement range of the sensor – Channel 1 (yellow) represents the trigger pulse sent to the sensor to initiate the measurement; Channel 2 (pink) shows the received high pulse from the transmission (approximately 20 ms after the trigger pulse), followed by a much lower pulse corresponding to the echo reflected from the target object (around 35 ms after transmission), and finally by free oscillations beyond the maximum measurement range (around 60 ms), which are characteristic of the sensor's internal circuit with a variable gain factor. The time interval between the trigger pulse and the transmission depends on the specific sensor and is used for its automatic internal calibration of coefficients and the determination of its noise floor.

Fig. 1. *Example Oscillogram A*

Oscillogram of the signal in the area of interest (Fig.2). The minimum signal level (approximately 1.2 V noise floor) is clearly visible, over which the useful signals from the transmission and reflection are superimposed, as well as the time interval between them (around 35 ms).

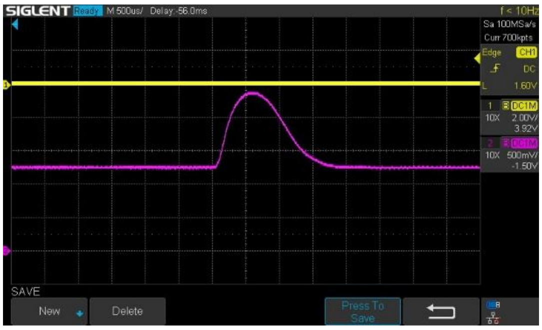

Fig. 2. Example Oscillogram B

Enlarged oscillogram of the reflected signal (fig.3). Through additional analysis of this waveform, the accuracy of the distance measurement can be further improved.

Fig. 3. *Example Oscillogram C*

Principle of Measurement: The system measures the time from the moment the ultrasonic pulses are emitted until the echo signal reflected from the object (in this case, the water surface) is received. This time is exactly twice the travel time of the sound in one direction, since the transmitter and receiver are the same component. Knowing the speed of sound in air, the distance to the object can be calculated as follows:

Speed of sound at (T_0 = 25°C):

V_s = 345 m/s

Time of flight (ToF) for both directions:

ToF = 35 ms

Distance to the object:

$$L = \frac{1}{2}(ToF \times V_s) = \frac{1}{2}(0.035 \times 345) = 6.0375 \text{ m} \qquad (1)$$

Since the speed of sound in air depends strongly on temperature (fig.4) and only slightly on humidity and pressure (fig.5), applying temperature correction (fig.6) is sufficient to achieve acceptable practical accuracy.

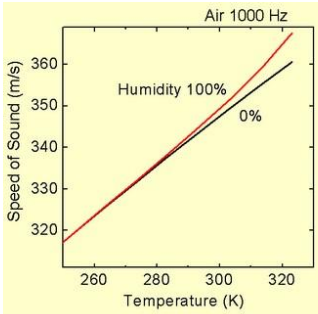

Fig. 4. *Speed of Sound vs. Temperature and Humidity*

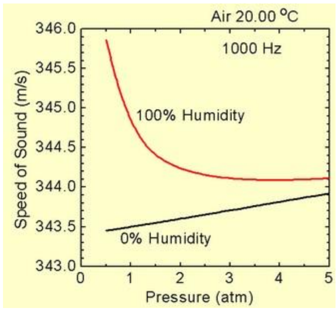

Fig. 5. *Speed of Sound vs. Pressure and Humidity*

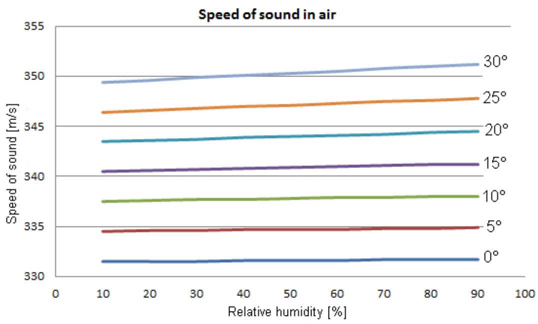

Fig. 6. *Speed of Sound in Air at Different Temperatures and Humidity Levels*

Ultrasonic Distance Measurement Module (Fig.7). The device represents a distance measurement system designed primarily for measuring the water level in open bodies such as rivers, reservoirs, and dams. It integrates an ultrasonic distance sensor capable of measuring up to 10 meters, a solar radiation shield equipped with an internal digital air temperature sensor, and a microcontroller responsible for signal processing, temperature correction, and communication with an external system via an RS485 interface. The microcontroller, its components, and the ultrasonic sensor share a common plastic enclosure, mounted beneath the solar radiation shield containing the thermometer. This configuration enables the measurement of air temperature in the immediate vicinity of the sensor, ensuring that the temperature correction of the measurement is as accurate as possible.

Fig. 7. *Ultrasonic Distance Measurement Module*

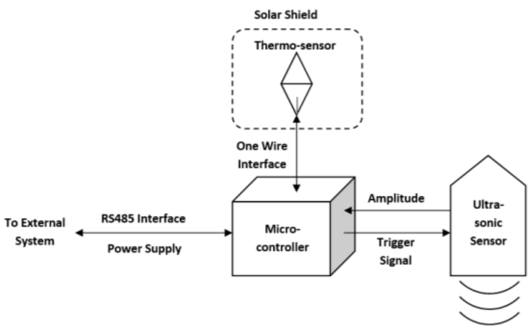

Fig. 8. *Block diagram of the module*

The solar radiation shield largely prevents the measurement of artificially elevated temperatures caused by direct sunlight on the thermometer. The movement of air through the shield — resulting from convection due to heating or wind — helps reduce the temperature measurement error and improves overall accuracy (fig.8).

Operating Algorithm:

The microcontroller initiates the measurement by generating a trigger pulse to the ultrasonic sensor and then waits for the amplitude signal, which it captures (digitizes) for subsequent processing and analysis to determine the time between the transmitted and received pulses. The speed of sound is then corrected according to the current temperature, and the distance to the water surface is calculated. The final result is obtained after processing a series of several measurements within approximately 1 second, with measurement cycles repeating every 30 seconds, meaning the water level is measured twice per minute.

CONCLUSION

This study presents the development and testing of a cloud-based ultrasonic system for river level measurement using the MB7076 XL-MaxSonar-WRLA1 sensor. The system combines optimized hardware design with intelligent algorithms for signal processing and temperature compensation, achieving errors below 3% in field conditions and up to 0.5% in laboratory tests.

The inclusion of a solar radiation shield and a Signal Quality Index (SQI) improves measurement stability and reliability under varying environmental conditions.

Overall, the results confirm that the proposed approach provides a cost-effective and accurate alternative to conventional radar-based monitoring systems. The developed solution contributes to the advancement of hydrological monitoring technologies and supports the implementation of sustainable water management and Smart City infrastructures.

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ultrasonic signal processing, and the communication module for remote monitoring of water levels.

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