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ВИКОРИСТАННЯ УЛЬТРАЗВУКОВИХ ДАТЧИКІВ НА БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТАХ ТА АНАЛІЗ ЇХНЬОЇ ТОЧНОСТІ

Безпілотні літальні апарати (БПЛА), широко відомі як дрони, стали важливою складовою сучасних технологічних систем. Протягом останнього десятиліття їхній розвиток значно прискорився, головним чином завдяки досягненням у галузі електроніки, вбудованих систем, сенсорних технологій та алгоритмів автономного керування. Сьогодні дрони вже не обмежуються лише рекреаційним використанням; вони широко застосовуються для промислових інспекцій, у сільському господарстві, моніторингу навколишнього середовища, рятувальних операціях, картографуванні місцевості, логістиці та системах безпеки.

Одним із ключових аспектів, що впливають на ефективність роботи дронів, є впровадження сенсорних систем. Датчики забезпечують отримання необхідної інформації про навколишнє середовище та поточний стан літального апарата. Без надійних даних від датчиків були б неможливими автономний політ, стабілізація та виявлення перешкод. Сучасні платформи БПЛА зазвичай інтегрують кілька сенсорних технологій, таких як гіроскопи, акселерометри, GPS-модулі, оптичні камери, системи LiDAR, інфрачервоні та ультразвукові датчики.

Серед цих технологій ультразвукові датчики є одним із найпростіших і найдоступніших рішень для вимірювання відстані на коротких дистанціях. Їхня мала вага, компактні розміри та відносно низьке енергоспоживання роблять їх придатними для інтеграції в легкі платформи дронів. Ультразвукові датчики найчастіше використовуються для стабілізації висоти польоту, автоматичної посадки, уникнення перешкод та навігації в приміщеннях, де сигнали GPS можуть бути недостатньо точними або взагалі недоступними.

Принцип роботи ультразвукових датчиків ґрунтується на передачі та прийомі високочастотних звукових хвиль. Після відбиття випроміненого акустичного сигналу від перешкоди датчик визначає час повернення відбитої хвилі та розраховує відстань між датчиком і об'єктом. Хоча сам принцип є відносно простим, на точність вимірювання можуть впливати різні фактори навколишнього середовища, зокрема температура, вологість повітря, вітер, матеріал поверхні та геометрія об'єкта вимірювання.

Попри певні обмеження, ультразвукові датчики продовжують широко використовуватися в навчальних, експериментальних та недорогих системах БПЛА. Їхні переваги особливо помітні в застосуваннях, де потрібні надійні вимірювання на коротких відстанях без використання дорогого обладнання.

Основною метою цієї статті є аналіз використання ультразвукових датчиків у системах дронів та експериментальна оцінка їхньої точності під час практичних вимірювань відстані. Експериментальна частина дослідження зосереджена на ультразвуковому датчику HC-SR04, підключеному до мікроконтролера Arduino Uno. Вимірювання проводилися в контрольованих умовах приміщення на різних відстанях з метою порівняння виміряних значень із фактичними відстанями та оцінки придатності датчика для застосування на безпілотних літальних апаратах.

Ключові слова: *датчик, ультразвук, відстань, навігація, засоби.*

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UTILIZATION OF ULTRASONIC SENSORS ON DRONES AND ANALYSIS OF THEIR ACCURACY

Unmanned aerial vehicles (UAVs), commonly referred to as drones, have become an increasingly important part of modern technological systems. Over the last decade, their development has accelerated significantly, mainly due to advances in electronics, embedded systems, sensor technologies, and autonomous control algorithms. Today, drones are no longer limited to recreational use; they are widely applied in industrial inspection, agriculture, environmental monitoring, rescue operations, terrain mapping, logistics, and security applications.

One of the key aspects influencing drone performance is the implementation of sensor systems. Sensors provide essential information about the surrounding environment and the current state of the aircraft. Without reliable sensor data, autonomous flight, stabilization, and obstacle detection would not be possible. Modern UAV platforms typically integrate multiple sensing technologies such as gyroscopes, accelerometers, GPS modules, optical cameras, LiDAR systems, infrared sensors, and ultrasonic sensors.

Among these technologies, ultrasonic sensors represent one of the simplest and most affordable solutions for short-range distance measurement. Their low weight, compact dimensions, and relatively low power consumption make them suitable for integration into lightweight drone platforms. Ultrasonic sensors are most commonly used for altitude stabilization, automatic landing, obstacle avoidance, and indoor navigation, where GPS signals may not be sufficiently accurate or available.

The operating principle of ultrasonic sensors is based on the transmission and reception of high-frequency sound waves. After the emitted acoustic signal reflects from an obstacle, the sensor evaluates the return time of the reflected wave and calculates the distance between the sensor and the object. Although the principle itself is relatively simple, measurement accuracy may be influenced by several environmental factors, including temperature, air humidity, wind, surface material, and the geometry of the measured obstacle.

Despite certain limitations, ultrasonic sensors continue to be widely used in educational, experimental, and low-cost UAV systems. Their advantages are particularly evident in applications that require reliable short-range measurements without the need for expensive hardware.

The main objective of this paper is to analyze the use of ultrasonic sensors in drone systems and experimentally evaluate their accuracy in practical distance measurements. The experimental part of the study focuses on the HC-SR04 ultrasonic sensor connected to an Arduino Uno microcontroller. Measurements were performed under controlled indoor conditions at various distances in order to compare measured values with actual distances and assess the suitability of the sensor for drone applications.

Keywords: *sensor, ultrasound, distance, guidance, means*

Unmanned aerial vehicles are flying systems capable of operating without the direct physical presence of a pilot onboard. Depending on the application, drones may be remotely controlled by an operator or perform autonomous tasks using onboard control units and integrated sensor technologies. In recent years, UAV systems have become increasingly important in both civilian and industrial sectors due to their flexibility, relatively low operating costs, and ability to access environments that may be dangerous or difficult for humans.

Current drone systems consist of several interconnected subsystems that ensure stable and safe operation. The basic components usually include a flight controller, electric motors, propellers, communication modules, a power supply system, and multiple sensors responsible for environmental perception and navigation.

Sensors play a crucial role in drone functionality because they continuously provide information required for flight stabilization and autonomous control. The most commonly used sensors include gyroscopes and accelerometers, which monitor angular movement and orientation, GPS modules for positioning, optical cameras for visual navigation, LiDAR systems for high-precision distance measurement, and ultrasonic sensors for short-range obstacle detection.

Gyroscopes and accelerometers are generally integrated into inertial measurement units (IMUs), which are essential for maintaining stable flight conditions. GPS modules allow drones to determine their geographical position and follow predefined routes. Optical cameras are frequently used for object recognition, aerial mapping, and monitoring applications. LiDAR systems provide highly accurate three-dimensional environmental scanning, although their implementation is usually associated with higher costs.

Ultrasonic sensors belong to the category of low-cost proximity sensors designed primarily for short-distance measurements. In drone systems, they are commonly positioned on the underside or sides of the aircraft to detect nearby obstacles or monitor altitude above the ground Fig. 1. Due to their relatively simple design and low hardware requirements, ultrasonic sensors are often integrated into educational and experimental UAV platforms.

One of the major advantages of drone systems is their ability to operate in environments that would otherwise expose humans to unnecessary risks. UAVs are widely used during rescue operations, industrial inspections at high altitudes, hazardous material monitoring, and surveillance missions. However, drone operation is still limited by several factors, including battery capacity, weather conditions, communication stability, and sensor reliability.

The combination of different sensor technologies significantly improves drone safety and navigation accuracy. Modern autonomous UAV systems therefore rely on sensor fusion, where information from multiple sensors is processed simultaneously in order to achieve more reliable environmental awareness and stable flight performance [1][2][3].

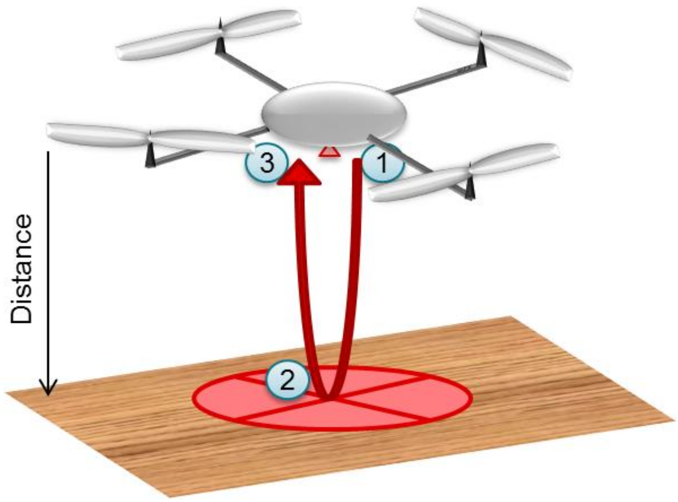

Fig. 1. **LiDAR systems, and ultrasonic sensors**

Ultrasonic Sensors and Their Operating Principle

Ultrasonic sensors are electronic devices designed for non-contact distance measurement. Their operation is based on the transmission of ultrasonic waves and the subsequent detection of reflected signals from surrounding objects. Due to their low price, compact dimensions, and relatively good measurement accuracy at short distances, these sensors are widely used in robotics, industrial automation, and unmanned aerial systems.

Ultrasound refers to mechanical sound waves with frequencies higher than the upper limit of human hearing, which is approximately 20 kHz. Most ultrasonic sensors used in electronic systems operate at frequencies close to 40 kHz. The sensor emits a short ultrasonic pulse into the surrounding environment, and after the wave reflects from an obstacle, the reflected signal is detected by the receiving element.

The distance between the sensor and the object is calculated from the measured travel time of the ultrasonic wave. The relationship between distance and signal propagation time can be expressed as:

$$d = \frac{v \cdot t}{2}$$

where:

- **d** is the distance to the object,
- **v** is the speed of sound in air,
- **t** is the time taken for the ultrasonic pulse to return.

The speed of sound in air at a temperature of 20 °C is approximately:

$$v = 343 \text{ m/s}$$

The measured value must be divided by two because the ultrasonic signal travels both toward the obstacle and back to the sensor.

Although ultrasonic sensors provide relatively reliable measurements at short distances, their accuracy may be affected by several environmental and physical factors. The most significant influences include:

- ambient temperature,
- air humidity,
- wind conditions,
- shape and material of the measured object,
- angle of incidence of the ultrasonic wave,
- electromagnetic interference.

One of the most frequently used sensors in educational and experimental projects is the HC-SR04 ultrasonic sensor Fig. 2. This module allows distance measurements approximately within the range of 2 cm to 400 cm under ideal operating conditions. The sensor typically achieves millimeter-level accuracy at shorter distances, making it suitable for simple autonomous systems and laboratory experiments [4][7].

In UAV applications, ultrasonic sensors are mainly used for low-altitude stabilization, automatic landing, obstacle detection, and autonomous indoor navigation. Their implementation is especially advantageous in confined environments where optical or GPS-based systems may not provide sufficient reliability.

The main advantages of ultrasonic sensors include low cost, easy integration into microcontroller systems, low power consumption, and relatively low weight. On the other hand, their disadvantages involve limited measurement range, lower reliability under outdoor conditions, and sensitivity to environmental disturbances such as wind or irregular reflective surfaces.

For this reason, ultrasonic sensors are often combined with additional sensing technologies such as cameras or LiDAR systems in professional UAV platforms [5][6][8].

Ultrasonic sensors are primarily used on drones for: measuring altitude above the ground, flight stabilization, automatic landing, detection of nearby obstacles, and autonomous indoor navigation.

Their advantages include low weight and simple integration into drone control systems. However, their disadvantages are a shorter range and lower reliability in outdoor environments under unfavorable conditions or at higher flight speeds.

Application of Ultrasonic Sensors on Drones

Ultrasonic sensors represent an important component of modern autonomous drone systems, particularly in applications requiring short-range environmental awareness. Their primary function is to provide continuous information about the distance between the drone and surrounding obstacles or the ground surface. This information is subsequently processed by the flight controller, which adjusts the drone's movement accordingly.

Fig. 2. **HC-SR04 sensor**

One of the most common applications of ultrasonic sensors in UAV systems is altitude measurement during low-altitude flight. Sensors mounted on the underside of the drone continuously monitor the distance between the aircraft and the ground. This enables stable hovering and precise altitude control, especially in indoor environments where GPS signals may be unavailable or inaccurate.

Ultrasonic sensors are also widely used during automatic landing procedures. During descent, the sensor continuously evaluates the remaining distance to the ground surface and allows the flight controller to gradually reduce motor power. As a result, the landing process becomes smoother and safer, minimizing the risk of sudden impact or instability.

Another important area of application is obstacle detection. Sensors positioned on the front, rear, or sides of the drone can identify nearby objects in real time. If an obstacle is detected within a critical distance, the control system may warn the operator or automatically modify the flight trajectory in order to avoid collision.

Indoor navigation represents another field where ultrasonic sensors can provide practical advantages. Since GPS-based positioning systems often perform poorly inside buildings, drones must rely on alternative methods for orientation and stabilization. In such cases, ultrasonic sensors may support autonomous movement and improve positional awareness.

Despite these advantages, ultrasonic sensors also have several limitations that restrict their use in more demanding applications. One of the major disadvantages is their relatively short measurement range compared to laser-based systems. Furthermore, measurement reliability may decrease under outdoor conditions due to wind, environmental noise, or irregular object surfaces.

The wider measurement angle of ultrasonic waves may also reduce precision when multiple nearby obstacles are present. In addition, highly absorbent or uneven materials may weaken the reflected signal and negatively affect measurement accuracy.

From a practical perspective, ultrasonic sensors are most suitable for short-range applications and lower flight altitudes. In modern professional UAV systems, they are therefore commonly combined with optical sensors, LiDAR systems, cameras, and inertial navigation systems to improve overall reliability and operational safety [2][3][9].

Practical Implementation of Measurement

The experimental part of this work focused on evaluating the accuracy of the HC-SR04 ultrasonic sensor during distance measurements under controlled conditions. The experiment was carried out using an Arduino Uno microcontroller, which processed the data obtained from the sensor.

The HC-SR04 module was selected because it represents one of the most commonly used ultrasonic sensors in educational and experimental electronics projects. Its popularity is mainly associated with low cost, simple operation, and straightforward integration into microcontroller-based systems.

The sensor was connected to the Arduino Uno according to the standard connection scheme. The TRIG pin was used to generate the ultrasonic pulse, while the ECHO pin received the reflected signal. The Arduino microcontroller subsequently calculated the distance based on the measured signal propagation time.

The experiment was conducted indoors under stable environmental conditions in order to minimize the influence of external disturbances such as wind or ambient noise. A flat solid obstacle was placed at predefined distances from the sensor.

Measurements were performed at distances ranging from 20 cm to 200 cm. Each measurement was repeated three times, and the resulting average value was calculated to improve reliability. Actual distances were verified using a standard measuring tape.

After the initialization process in the Arduino IDE environment, the sensor repeatedly emitted ultrasonic pulses into space. When the transmitted wave reflected from the obstacle, the returning signal was captured through the ECHO pin. Based on the measured time interval, the Arduino microcontroller calculated the corresponding distance.

The collected measurement data were subsequently compared with the actual distances in order to evaluate sensor accuracy and identify possible deviations. The connection schematic is shown in Fig. 3.

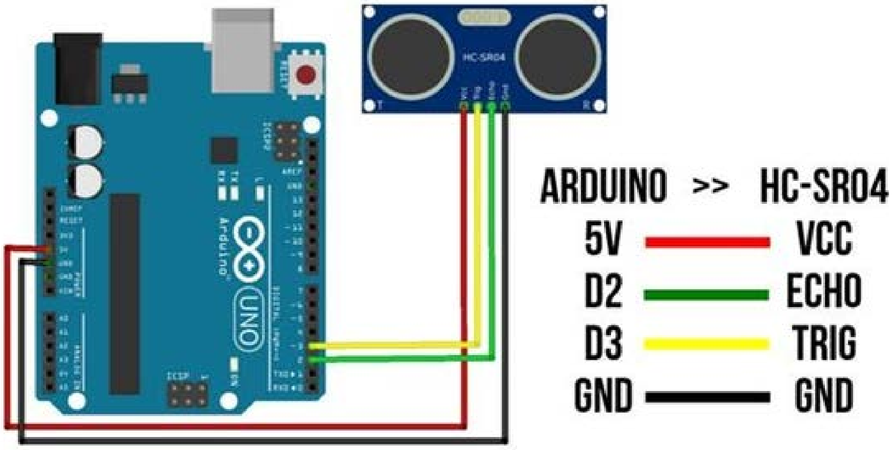

Fig. 3. **Connection schematic**

Measurement Results

The purpose of the experiment was to evaluate the accuracy of the HC-SR04 ultrasonic sensor during practical distance measurements. All measurements were carried out under stable indoor conditions in order to reduce the influence of environmental interference.

Measured values were obtained at several predefined distances between 20 cm and 200 cm. Each measurement was repeated three times, and the average value was calculated to ensure greater reliability and consistency of the results.

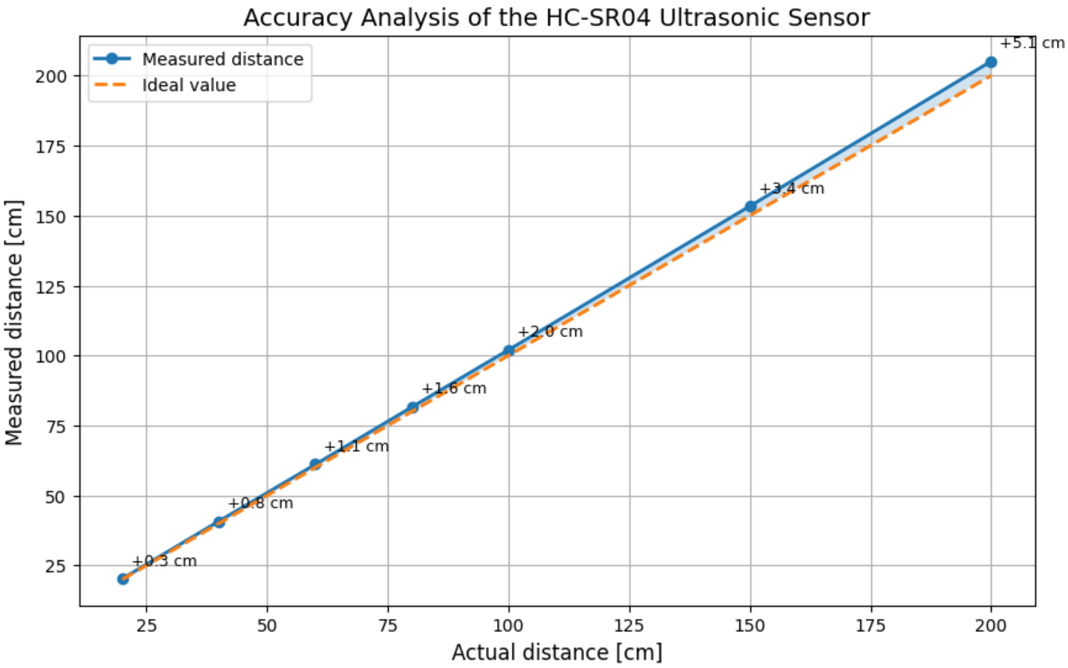

Fig. 4. **Accuracy analysys of HC-SR04 ultrasonic sensor**

The graphical evaluation of the experiment demonstrated that the relationship between actual and measured distances remained almost linear throughout the majority of the measurement range. The measured values closely followed the ideal reference line, particularly at shorter distances.

Within the range of approximately 20 cm to 80 cm, the differences between actual and measured values were minimal. This indicates that the HC-SR04 sensor provides relatively stable and accurate measurements under short-range operating conditions.

As the measured distance increased, the deviation between actual and measured values gradually became more noticeable. The largest deviation occurred at a distance of approximately 200 cm, where the measured value exceeded the actual distance by roughly 5 cm.

Although the measurement error increased with distance, the recorded values still showed relatively smooth progression without significant random fluctuations. This confirms that the sensor measurements remained repeatable and sufficiently stable for simple autonomous applications.

The obtained results indicate that the HC-SR04 ultrasonic sensor is most suitable for applications involving short-distance measurements. In drone systems, this includes low-altitude stabilization, automatic landing procedures, and obstacle detection within the immediate surroundings of the aircraft.

The experiment also confirmed several practical limitations of ultrasonic sensing technology. Measurement accuracy may decrease at longer distances, and sensor performance can be negatively influenced by environmental conditions or reflective properties of the measured object.

Nevertheless, considering its simplicity, affordability, and relatively reliable short-range performance, the HC-SR04 sensor remains a practical solution for educational projects and basic UAV applications [6][11].

Concluion

The objective of this paper was to analyze the utilization of ultrasonic sensors in drone systems and experimentally evaluate their accuracy during practical distance measurements. The theoretical section introduced the operating principles of UAV sensor systems and described the functionality of ultrasonic sensors commonly used in autonomous navigation applications.

The experimental part focused on practical measurements using the HC-SR04 ultrasonic sensor connected to an Arduino Uno microcontroller. Measurements were carried out at several predefined distances under stable indoor conditions, and the obtained values were compared with actual measured distances.

The results demonstrated that the ultrasonic sensor provides relatively accurate and stable measurements at shorter distances. The graphical analysis confirmed that the measured values closely approximated the ideal reference values, especially within lower measurement ranges. However, as the distance increased, the measurement error gradually became more significant, which represents a natural limitation of ultrasonic sensing technology.

Based on the performed experiment, it can be concluded that ultrasonic sensors are particularly suitable for simple autonomous drone applications involving short-range measurements. Typical examples include low-altitude flight stabilization, automatic landing, indoor navigation, and nearby obstacle detection.

The main advantages of ultrasonic sensors include low implementation cost, low weight, simple integration into electronic systems, and low power consumption. Their disadvantages involve limited measurement range and sensitivity to environmental conditions such as wind, temperature changes, or irregular object surfaces.

In professional UAV systems, ultrasonic sensors are therefore often combined with additional technologies such as LiDAR systems, optical sensors, and cameras in order to improve navigation accuracy and operational reliability. Despite their limitations, ultrasonic sensors remain an effective and economically accessible solution for educational, laboratory, and experimental drone applications.

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