Methods of increasing the accuracy of determining the place of occurrence of out-of-state situations in multimedia data storage facilities of IoT systems

Andriy Dudnik[1,2,3,4,†], Dmytro Kvashuk[4,†], Andriy Fesenko[4,5,*,†], Larysa Myrutenko[1,†] and Vadym Rakytskyi[4,†]

[1] *Taras Shevchenko National University of Kyiv, Volodymyrska Str., 60, Kyiv, 01601, Ukraine*
[2] *Interregional Academy of Personnel Management, Frometivska Str., 2, Kyiv, 03039, Ukraine*
[3] *Open University of Human Development "Ukraine", Lvivs'ka Str., 23, Kyiv, 04071, Ukraine*
[4] *National Aviation University, Liubomyra Huzara Ave. 1, Kyiv, 03058, Ukraine*
[5] *State Scientific and Research Institute of Cybersecurity Technologies and Information Protection, Maksym Zalizniak Str., 3/6, Kyiv, 03142, Ukraine*

Abstract

The software product is proposed for performing the dispatching task of distributing water A method for determining the location of out-of-state situations using the SDS-TWR method is proposed, which allows you to accurately establish the radius of their potential occurrence in the multimedia data store. A new informative parameter for measuring the distance between radio modules located in the multimedia data storage is presented, which is based on the control of the rotational parameters of the direct current electric motor. A new approach to distance measurement is used, which includes the procedure of converting the power of a radio signal into a PWM signal, which affects the speed of rotation of the shaft of an electric motor, which controls a special generator of the frequency of the light flux. Such a procedure allows not only to determine the distance between radio modules, but also to transmit information containing data on the penetration of multimedia data storage using optical communication. The presented technique opens up new prospects for determining the locations of occurrence of emergency situations related to the penetration of multimedia data storage, in the absence of a signal or its insufficient power for data transmission.

Keywords

Measurement, torque, electric motor, wireless sensor networks, emergency detection, ZigBee, location, GPS, multimedia data storage, video transmission

1. Introduction

Wireless sensor networks are rapidly gaining popularity due to their versatility and wide range of applications. An important aspect of such networks is the ability to accurately determine the geographical position of their components, which is necessary for the effective operation of the system of monitoring and control of multimedia data storage. Therefore, there is a need to collect data related to various physical parameters of such components, such as movement, distance between them, temperature, signal strength, etc. For this, a variety of sensors are used that can measure and store important indicators. The number of objects in a sensor network can be significant, which provides ample opportunities for data analysis and management. However, the presence of a large number of objects in the network introduces its own difficulties, in particular, in determining the exact location of each of them. This requires high accuracy and reliability in

CH&CMiGIN'24: Third International Conference on Cyber Hygiene & Conflict Management in Global Information Networks, January 24–27, 2024, Kyiv, Ukraine

* Corresponding author.
† These authors contributed equally.
a.s.dudnik@gmail.com (A. Dudnik); 1619823@gmail.com (D. Kvashuk); aafesenko88@gmail.com (A. Fesenko); myrutenko.lara@gmail.com (L. Myrutenko); rvadim4835@gmail.com (V. Rakytskyi)
0000-0003-1339-7820 (A. Dudnik); 0000-0002-4591-8881 (D. Kvashuk); 0000-0001-5154-5324 (A. Fesenko); 0000-0003-1686-261X (L. Myrutenko); 0000-0002-4046-266X (V. Rakytskyi)

positioning and navigation systems. Traditional methods such as Time of Arrival (ToA) and Time Difference of Arrival (TDoA), although effective, still have certain limitations, especially in terms of accuracy and reliability when used over long distances. In the context of the development of the Internet of Things (IoT) and wireless technologies, there is a need to develop new, more effective methods for determining the location of objects. One such method is Symmetric Double Sided Two Way Ranging (SDS-TWR), which offers to solve the problems associated with inaccuracies in determining the distance.

The SDS-TWR method opens up new opportunities for accurate determination of object coordinates, which is an important aspect in the deployment and management of modern wireless sensor networks. At the same time, scientists are trying to get an additional informative parameter for distance measurement, based on signal strength, but face the problem of the influence of the environment on the signal. This includes interference, such as reflection, absorption, and scattering of the signal, which can significantly distort the distance estimate. These factors can affect the reliability and accuracy of measurements, especially in challenging environments such as urban landscapes or densely populated industrial areas where multiple interferences and various noise sources are possible. Therefore, there is a need to create a new principle of transmitting information about the state of signal strength, or its absence in general.

2. Review of existing solutions and literature sources

Considering the various methods of estimating the distance between two nodes by measuring the signal propagation time, the most popular ones should be highlighted. One of the simplest methods is the use of Time of Arrival (ToA), where the distance is determined in direct proportion to the time required for a signal to travel from one node to another. This method requires precise synchronization between nodes.

Another method, Time Difference of Arrival (TDoA), is based on determining the difference in the time of arrival of a signal from one node to several other nodes, or between several signals that arrive from one node to another. This method is widely used in cellular communication and requires synchronization of receiving nodes. Also, this method often requires additional equipment to transmit different types of signals, such as radio and ultrasound signals. Ultrasonic techniques used in conjunction with radio signals can provide measurements accurate to within a few centimeters. However, these methods have limitations, such as high cost, which is associated with the need to use additional equipment. In addition, there are limitations associated with the range of the ultrasound signal. Studies that have been conducted to evaluate bit errors (BER) and signal-to-noise ratio (SNR) with changes in noise power and data rate have shown that the level of signal power depends on many factors, the vast majority of which are caused by electromagnetic interference [1]. But taking into account the fact that when applying such methods it is difficult to obtain high accuracy, it is indicated in the work [2] that RSSI can be used to determine the location, if the error is 3-5 m.

A study based on the analysis of the paper [3] evaluated the effect of frame size on data delay in ZigBee system, especially when the RSSI value changes. This is quite important for delay-sensitive applications such as video data. The study helps to understand how changes in the frames transmitted by the ZigBee coordinator to the end nodes and vice versa affect the delay. It also expands on previous findings that distance between ZigBee modules affects signal strength by focusing on analyzing parameters that affect ZigBee communication indoors rather than outdoors. However, the problem of estimating RSSI without taking into account signal losses and additional interference also needs to be solved. This requires the search for new information parameters.

The article [4] presents a method for measuring distances between devices conforming to the IEEE 802.15.4 (ZigBee) standard, which uses a 2.45 GHz chip. The technique is based on the use of standard communication packages for simultaneous data transmission and localization. To increase the accuracy of positioning in difficult conditions, the method of coherent synthesis of measurements in different channels and estimation of the signal phase is applied, allowing the use of the full ISM bandwidth of 80 MHz. The experiments showed a positioning error of less than 16 cm and 9 cm with a standard deviation of less than 3 cm and 1 cm, respectively, demonstrating a significant improvement in accuracy compared to traditional methods. However, in the studies that were conducted, the influence of the dependence of radio interference, which can significantly change the characteristics of the obtained results, was not taken into account.

Thus, taking into account a number of features related to destabilizing factors, there is a need to create new ways of measuring the distance between radio modules based on additional informative parameters. In such conditions, it is important to consider the possibility of transmitting information in the absence of sufficient power of the radio transmitter.

In this paper, the method using ToA and the TDoA method are compared with the Symmetric Double Sided Two Way Ranging (SDS-TWR) method, which is proposed to solve the problem of increasing distance measurement error. At the same time, a new method of converting the power of the received radio signal into the mechanical moment of the electric motor is proposed to build a scale for visualizing the distance between the transmitter and the receiver of the radio signal. This will allow the construction of a distance measuring device to determine the location of an intrusion into a multimedia data store based on RSSI data.

3. Methodology for the study of means of determining the position

There are a number of technologies that use different approaches to measuring distances using radio signals to determine the location of a transmission node. The most popular are the methods based on the determination of the power of the input signal (Receive Signal Strength Indication), time of signal passage (Time of Flight), phase shift of radio waves (Phase Difference) and determination of the angle to the object (Angular Positioning). Due to the structural difficulties in the organization of the last method and the relative high cost of the second-to-last method, methods based on determining the power of the received signal and calculating the signal transit time have become most widespread [5, 6].

The SDS-TWR technology utilizes a modification of the Time of Flight method named Symmetric Double Sided Two Way Ranging (SDSTWR). SDSTWR is an advancement of the Round Trip Time (RTT) method. To measure distances using RTT between objects A and B, object A sends a measurement request packet to object B and records the sending time. Upon receiving the packet from A, object B sends back an acknowledgment packet (ACK) to A. Object A, upon receiving the ACK packet, records its arrival time.

The RTT method employs hardware-generated ACK packets, assuming equal packet processing time for both objects. The sending time of the measurement request packet and the receipt of the ACK packet are also hardware-recorded. This setup allows for the predetermination of packet processing time and the calculation of the signal propagation time (t_p) using a specific formula [7]:

$$t_p = \frac{T_{RTT} - T_{replay}}{2}, \tag{1}$$

where T_{RTT} is the time measured by object A from the moment of sending a packet to object B until receiving an ACK packet from object B; T_{replay} is the time measured by entity B from receiving a packet from entity A to sending an ACK packet. Given the speed of signal propagation in the environment of a known and constant value, it is easy to calculate the distance between objects.

The accuracy of measuring time intervals, and therefore distances, is significantly affected by the frequency stability of crystals used in transceiver modules when using SDS-TWR technology. The degree of accuracy is characterized by the error value ppm (parts per million), for convenience, it is written in whole numbers. A value of 1 ppm corresponds to an error of 0.0001%, or 10^{-6}. For example, for a crystal with a nominal frequency of 4 MHz and a frequency stability of 1 ppm, the maximum frequency deviation from the nominal will be 4000000 x 10^{-6} = 4 Hz.

Consider the effect of the ppm crystal on distance measurement. Suppose that the system consists of two objects, A and B, and their clocks run at the same speed.

Generally, packet distribution time is much shorter for T_{RTT} and T_{replay} . The time t_p, (s) usually does not exceed a few tens per second, and T_{RTT} and T_{replay} are often about 1 ms or more

$$t_p = \frac{(1{,}000074 \times 10^{-3} - 1{,}000014 \times 10^{-3})}{2} = 30 \times 10^{-9}. \quad (2)$$

Example:

Consider what happens if the clocks of object A and B have different speeds, for example +10 ppm and -10 ppm respectively

$$t_p = \frac{1{,}000074 \cdot 10^{-3} \cdot (1 + 10 \cdot 10^{-6}) - 1{,}000014 \cdot 10^{-3} \cdot (1 - 10 \cdot 10^{-6})}{2} = 40 \cdot 10^{-9}. \quad (3)$$

It is obvious that the error arises as a result of accepting the difference between large quantities measured with different precision. The main improvement of the SDS TWR method is aimed at eliminating this effect associated with different clock drift rates on different objects. To do this, the distances are measured on both sides, resulting in an average value being calculated.

Considering that $T_{reply\ A}$ ~ $T_{reply\ B}$, the signal propagation time t_p can be calculated by the formula [5]:

$$t_p = \frac{[(T_{RTT\ A} - T_{replay\ A}) + (T_{RTT\ B} - T_{replay\ B})]}{4}. \quad (4)$$

When analyzing the expression, it can be seen that the difference between the values measured by one clock is included in each of the brackets. In particular, it should be noted that this formula is applicable if $T_{reply\ A}$ ~ $T_{reply\ B}$, therefore, the greater the difference between these times, the greater the distance measurement error.

Thus, the SDSTWR method makes it possible to use less stable crystals, which fundamentally reduces the cost of the equipment used and at the same time ensures acceptable accuracy of distance determination. It is these important prerequisites that led to the emergence of promising SDS-TWR technology. In addition, it should be noted that since the fixation of the values of all times is carried out by the hardware part of the transceiver, the parameters and operating modes of the controlling microcontroller in no way affect the accuracy of determining the distances [6, 7]. However, it is important to preserve the integrity of the signal in conditions of individual interference. Thus, studies that have been conducted to evaluate bit error (BER) and signal-to-noise ratio (SNR) with changes in noise power and data rate have shown that the level of signal strength depends on many factors, the vast majority of which are caused by electromagnetic interference [8, 9].

4. Experimental studies

To conduct experimental research, distance measurement experiments were performed in wireless sensor networks using the Cisco Packet Tracer program. Let's create a network model using various devices connected by wireless channels. The main attention is paid to the interaction of the server and the network gateway. Experiments will include distance measurement using SDS-TWR radio modules and ATmega644 microcontrollers.

An analysis of emergency detection scenarios will be conducted and an automated data recording system will be used. Experiments will be conducted in an open area using different methods to confirm the accuracy of the measurements. The Cisco Packet Tracer program was launched and the necessary items were selected: motion detector, web camera, server and ZigBee home gateway in the device panel (Figure 1). The multimedia storage and the network gateway are connected by a wireless channel (FastEthernet0 and Ethernet1).

This model represents only a single segment of a distributed network, not the entire network, which consists of many segments of the same type and can extend over large distances depending on the area.

Found all the necessary elements for the construction of the model. This requires a smoke detector, a gate, a siren, a ZigBee home gateway, and a smartphone. The smoke sensor, siren, and gateway are connected to the gateway with a direct cable (fa0/1 - 01, fa0 - 0/3, fa0 - 0/2) (Figure 2).

All experiments used radio modules consisting of an SDS-TWR transceiver and an ATmega644 microcontroller (Figure 3). The microcontroller, which was proposed to be used inside the DCL 100 (Figure 1) and DCL 10 0/2 (Figure 2) devices, acted as the master on the SPI bus.

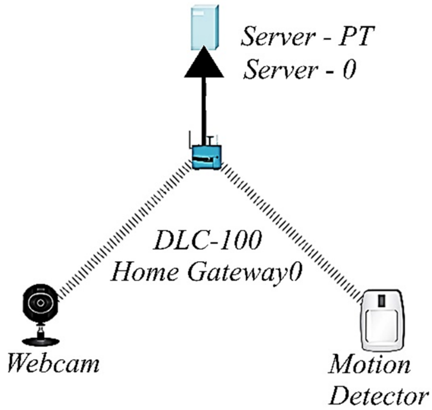

Figure 1: Model of a network segment for emergency detection of protected objects.

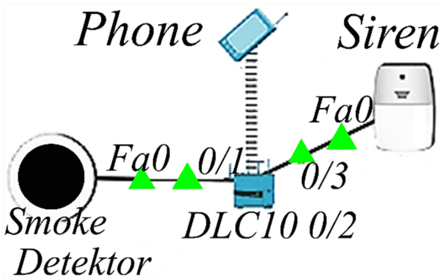

Figure 2: Segmental fire alarm model.

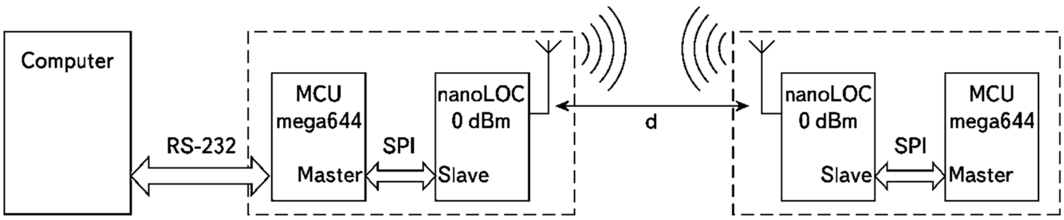

Figure 3: Model of the fire alarm segment.

The calculation of the distance between devices is introduced to duplicate the functions of the intrusion prevention system, in case of failure of the camera, infrared motion sensor, or smoke sensor. If it is known that all devices are stationary and the position of the sensors does not change, and in some segments, in the absence of changes in other segments, there is an increase in the signal delivery time from the master device to the slave device, this may indicate an emergency situation (intrusion of foreign objects, fire, or smoke). It is known that the listed phenomena reduce the signal level. You should pay attention to this segment. Therefore, further research on the calculation of the distance between sensor network devices is useful from the point of view of localization of the radius of a possible emergency situation, in case of failure of other systems.

The Master module was connected to the Server-PT computer (Figure 1) through an RS232 interface (Figure 3) with a specially written program for automated recording of measurement results, which in most experiments were received once per second. Namely, experiment number, measurement number, current date and time, actual distance measured with a tape measure or laser rangefinder, as well as the result of distance measurement using SDS-TWR technology. The output power of the radio signal was 1 mW. The stationary radio module (Master) was most often fixed on a wooden stand 0.8 m high, and the mobile one (Slave) on a wooden pole 1.8 m long. Transceivers were equipped with standard antennas of the M04S type (1/2-wave dipole).

The experiment consisted in measuring the distance in an open space next to the road surface along an asphalt road. Both modules were fixed on poles at a height of 1.5 m from the road surface in the direct line of sight of each other. The stationary module (Master) was connected to the computer. The second module (Slave) was carried along the road by one of the experiment participants. In Figure 4 you can see the curves obtained by averaging the results of 10 measurements.

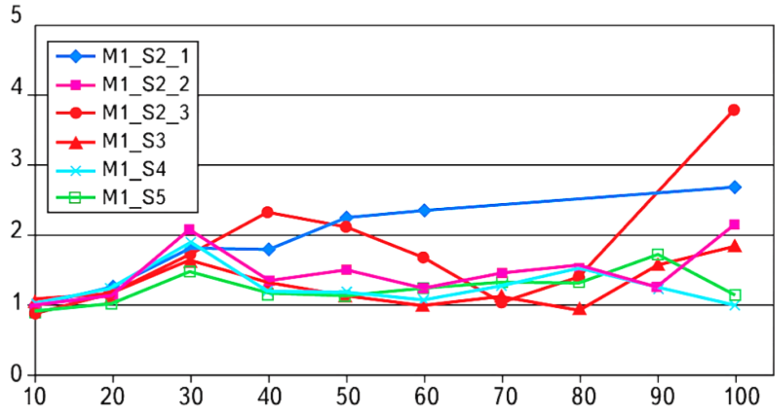

Figure 4: Deviation of the distances measured by the radio method from the real ones.

The horizontal axis shows the actual distance in meters and the vertical axis shows the difference between the SDS-TWR measured and the actual distance (also in meters): the measured distance is always greater than the actual distance due to the packet propagation technology used. The time may increase due to emergency situations. Situations where a false measurement point is supplemented by a 90% confidence interval for the mean value (Figure 5).

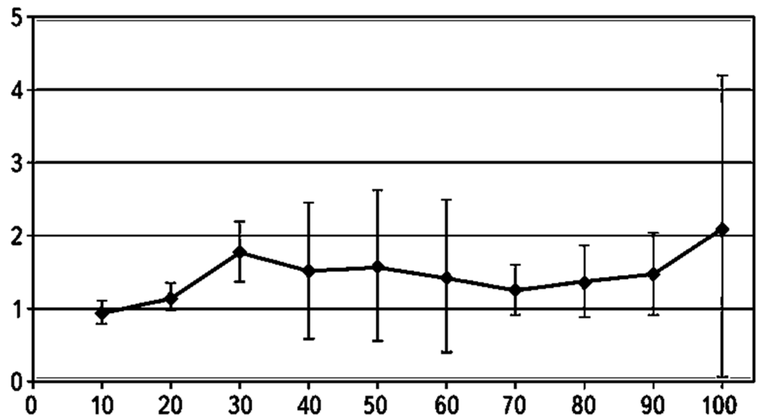

Figure 5: The result of averaging the values for all 6 experiments.

The first three curves were obtained on different days for one pair of modules (Master - 1, Slave - 2), on the remaining curves the Slave modules were changed.

In this way, it was possible to propose a model of the system for identifying emergency situations, which allows you to determine the radius of their possible occurrence in case of failure of the main systems. Based on the conducted experiments, the main conclusions can be drawn:

The applied radio modules of the SDS-TWR method allow quite accurate measurement of distances. In this case, the measurement results are slightly overestimated (depending on the external conditions), which may also indicate the occurrence of emergency situations.

Given that two main methods can be used to determine the distance: ToF (Time of Flight) and with the help of RSSI, to obtain an additional informative parameter, you can supplement the RSSI (Received Signal Strength Indicator) measurement procedure, which provides an estimate of the radio signal strength , which is received by the wireless device.

So, the built-in software of the device, built on the IEEE 802.15.4 (ZigBee) standard, measures the strength of the received signal. Signal strength is determined by the amplitude of the received signal and is expressed in decibels relative to milliwatts (dBm). The signal amplitude can be defined as the maximum deviation of the signal from its average value. The conversion of signal amplitude into decibels can be represented as follows [10–15]:

$$dBm = 10 \cdot lg\left(\frac{P}{\mathrm{mW}}\right), \tag{5}$$

where P is the signal power in milliwatts.

But there is a certain drawback of this method: the accuracy depends on the distance. This method works perfectly only in an open area. Obstacles and reflective surfaces significantly reduce accuracy. However, this method is very easy to implement at the hardware level, problems will arise only when calculating the distance on the computing server. Therefore, it is recommended to use two methods at the same time to accurately measure distances.

At the hardware level, the process is relatively simple. The beacon periodically sends signals to the base station. The base station, in turn, records the device identifier, received signal strength (RSSI) and packet arrival time. The last parameter is critically important for tracking the object's route. The collected information is transferred to the server, where further analysis and calculations take place. But, if the hardware part of the system is relatively simple to implement, data processing and analysis on the server require more complex calculations.

According to the Fries signal transmission equation, we have the dependence of the distance between radio modules on a number of known signal power parameters and antenna gain coefficients [16–18]:

$$R = \sqrt{\frac{P_t G_{Tx} G_{Rx}}{P_r}} \cdot \frac{\lambda}{4\pi}, \tag{6}$$

where R is the distance between the transmitter and the receiver; P_t - signal power emitted by the transmitter; G_{Tx} - antenna gain of the transmitter; G_{Rx} - gain coefficient of the receiver antenna; P_r - received signal power; λ is the wavelength of the signal, which is calculated as , where c is the speed of light, and f is the frequency of the signal; 4π is a constant that reflects the spherical propagation of a wave in three-dimensional space.

The P_r parameter using a module that complies with the IEEE 802.15.4 (ZigBee) standard can be obtained programmatically by connecting to it using a standard interface. Data processing is implemented on the basis of a microcontroller, which processes the parameters received from the network and calculates them using expression (2).

In this way, the transmission of received data can be carried out by a frequency method, using laser beams as a data transmission channel. To create frequency characteristics, the calculated distance indicator can be transformed into the electric power of a microelectric motor, which creates periodic pulses of the world flow, which are directed to a separate receiver (Figure 6). The frequency characteristics of such pulses can be obtained in a number of ways (a special receiver with photo-sensitive elements, a high-speed video camera, etc.).

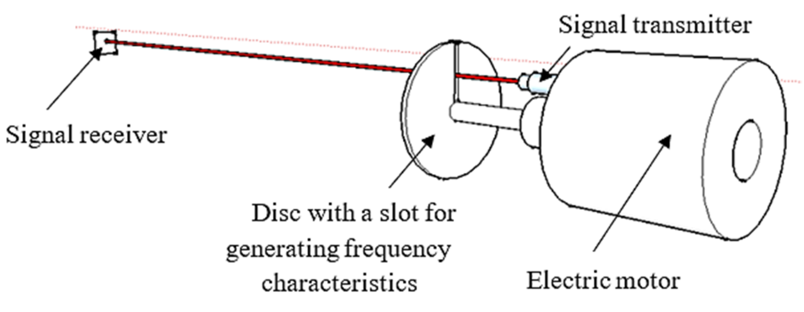

Figure 6: The method of transmitting the frequency characteristics of a signal using an electric motor.

The speed of rotation of the electric motor shaft can have a linear dependence on the R parameter, if it is converted into the frequency characteristics of the world flow of the transmission channel. For this, a PWM signal was generated at the output of the microcontroller to control the commutating electric motor with a device such as the IRF740 field-effect transistor. In turn, this will allow you to adjust the power of the electric motor depending on the width of the pulse that will be generated by the microcontroller. In this way, measuring the distance between radio modules will be provided with a new informative parameter, namely the frequency of rotation of the current electric motor shaft, which can be removed by a wide range of means. So, the intensity of the received signal (RSSI) is determined by receiving data from the radio module, then a control PWM signal is formed in the microcontroller, which switches the power transistor to control the power of the electric motor. The rotary motion of the electric motor disk generates the frequency characteristics of the global beam, which is directed at the receiving device. Thus, we obtain a linear relationship between the intensity of the received signal and the frequency characteristics of the light signal. In Figure 7. the procedure is presented, which includes obtaining RSSI - 1, converting the PWM signal level to control the power of the electric motor - 2, obtaining the frequency characteristics of the light signal - 3, as well as the possibility of their transmission by generating an optical signal, the frequency of which varies in proportion to the signal power [19–22]. This, in turn, allows to receive a signal at long distances, regardless of radio interference. For this, you can use any frequency meter or oscilloscope that can determine the frequency characteristics obtained by the optical receiver 4.

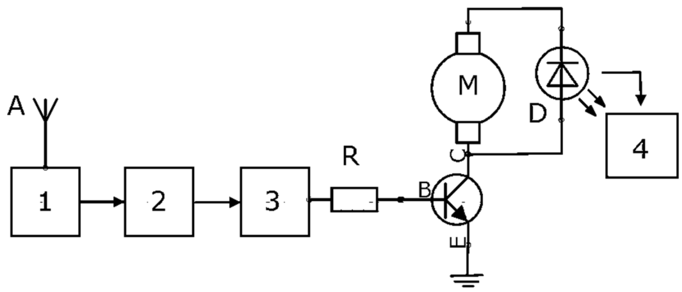

Figure 7: Procedure for converting RSSI into frequency characteristics of a pulse signal.

For an asynchronous electric motor, the dependence of power on the amplitude and frequency of the PWM signal can be expressed using the well-known ratio:

$$P = I_{short} \cdot \left(\frac{1 - 2e^{-\frac{T_0 + \Delta T}{2T_E}} + e^{-\frac{T_0}{T_E}}}{1 - e^{-\frac{T_0}{T_E}}} - \frac{\Delta T}{T_0} \right),$$

$$I_K = \frac{U_0}{R_\Sigma}, \Delta T = \frac{i_{\mathrm{giv}_i} T_3}{I_{short}}, \quad T_E = \frac{L_\Sigma}{R_\Sigma}, \quad T_0 = \frac{1}{f_{PWM}}, R_\Sigma = R_1 + R_2' + \frac{R_2'}{s}, \tag{7}$$

$$s = \frac{\omega_0 - \omega}{\omega_0}, \qquad i_{\mathrm{giv}_i} = I_3 \cdot sin\left(\omega_0 t - \frac{2 \cdot \pi \cdot (i-1)}{3}\right),$$

where: i – phase; t - current time; U_0– voltage at the output of the constant voltage source; i_{giv_i} - the current value of the average current task in phase i; f_{PWM}- frequency of PWM modulation; T_0- PWM modulation period; ΔT - the difference in the rise and fall times of the current during the PWM period; L_Σ- total inductance of the load circuit of the autonomous inverter; R_Σ- the total resistance of the load circuit of the autonomous inverter; R_1- Stator circuit resistance; R_2'- induced resistance of the rotor chain; T_E- electromagnetic time constant of the power supply chain; I_{short}- Short-circuit current of the power supply circuit; s - slippage of the asynchronous motor rotor; ω - angular frequency of rotation of an asynchronous motor; ω_0- angular frequency of the signal that sets the current of the asynchronous motor.

At the same time, the use of an asynchronous electric motor to solve these problems will not be the best solution, since the need to convert constant voltage into an alternating one, providing a control system for an asynchronous electric motor will create certain difficulties.

Therefore, it is necessary to determine the dependence of RSSI on the frequency of rotation of the electric motor, which will allow obtaining the frequency characteristics of the output signal in proportion to the strength of the radio signal level received by the transmitter.

To modify the expression (6) characterizing the distance by the RSSI method, where Pr is determined by the PWM signal fill factor and the motor shaft rotation frequency, we can use the known dependences of the shaft rotation speed on the voltage and the PWM fill factor.

First, consider the standard dependence of shaft rotation speed on electrical parameters for a DC motor:

$$\omega = k_v \cdot (D \cdot U_{\max} - I \cdot R), \tag{8}$$

where ω is the shaft rotation speed, k_v is the motor constant, I is the current, R is the internal resistance of the stator coils; $U_{\max}$ - maximum voltage; D is the PWM fill factor

Then we modify (6) and obtain an equation that characterizes the linear dependence of the distance between the radio modules and the frequency of rotation of the electric motor shaft according to the proposed measurement procedure (see Figure 2):

$$k_v \cdot (D \cdot U_{\max} - I \cdot R) = \frac{P_t \cdot G_{Tx} \cdot G_{Rx} \cdot \left(\frac{\lambda}{4\pi}\right)^2}{R^2}. \tag{9}$$

Thus, the use of an additional informative parameter will allow to increase the accuracy of distance measurement by the RSSI method, since the signal transmission channel based on a laser beam does not depend on radio interference, has almost no delay and does not require additional calibration during operation. For example, two measurement methods were simulated, using (6), where P_r is obtained using a random generator of additional radio interference, and based on (9), where the signal strength does not depend on radio interference in the range of 0-1000 m, but depends on parameters of the electric motor (Figure 8).

As a result of the simulation, we can see that the signal after transmission by the optical method is more stable, however, additional pulses are smoothed out due to inertia. Therefore, this method requires additional research related to the selection of optimal parameters of the electric motor.

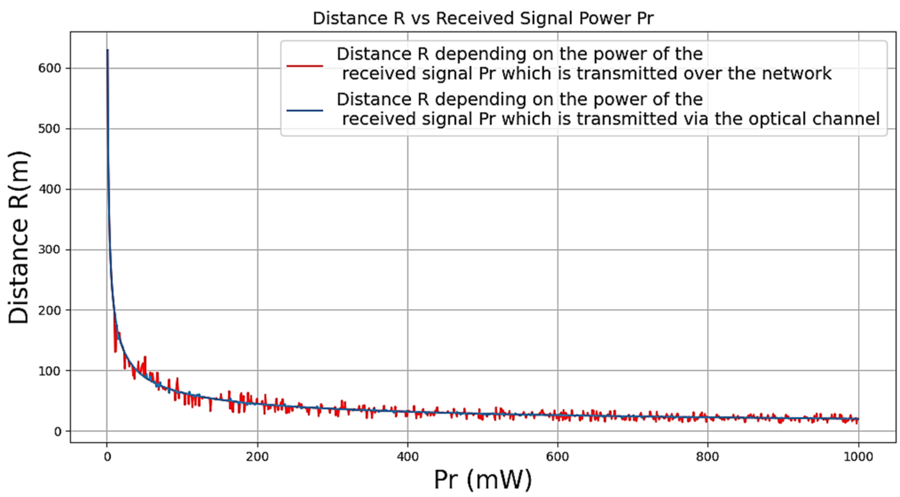

Figure 8: Dependence of distance on RSSI between radio modules according to expressions (6) and (9).

5. Conclusions

The SDS-TWR distance measurement error was found to be within 1–4 m and the random error of each measurement to be within ± 80 cm (90% confidence interval) and virtually independent of distance.

The use of an additional informative parameter significantly increases the accuracy of distance measurement by the RSSI method. The peculiarity of this method is that the signal transmission channel based on the laser beam does not depend on radio interference, has almost no delay and does not require additional calibration during operation. In the simulation of two methods of measurement, different conditions of signal reception were taken into account: in the first case (6), the dependence was obtained using a random generator for additional radio interference, and in the second (9) the signal strength did not depend on radio interference in the range of 0-1000 m, but depended from the parameters of the electric motor.

Thus, the main advantage of using a laser channel for transmitting the frequency characteristics of the signal power is that it is possible to avoid the influence of external interference, which ensures more stable and reliable transmission of video data about the occurrence of an off-state situation in the multimedia data storage.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

References

[1] K. Gill, S. -H. Yang, F. Yaoб X. Lu, A zigbee-based home automation system, IEEE Transactions on Consumer Electronics 55(2) (2009) 422–430. doi: 10.1109/TCE.2009.5174403.

[2] K. Subaashini, G. Dhivya, R. Pitchiah, ZigBee RF signal strength for indoor location sensing-Experiments and results, in: Proceedings of 2013 15th International Conference on Advanced Communications Technology, IEEE, PyeongChang, Korea (South), 2012, pp. 12–17.

[3] K. Tang, J. Chen, X. Yue, J. Tao, Y. Yan, The research on location method of partial discharge in switchgear based on radio frequency sensors and time difference of arrival algorithm, in: Proceedings of 6th Information Technology and Mechatronics Engineering Conference, (Chongqing, China, 2022, pp. 326–331. doi: 10.1109/ITOEC53115.2022.9734325.

[4] S. Schwarzer, M. Vossiek, M. Pichler, A. Stelzer, Precise distance measurement with IEEE 802.15.4 (ZigBee) devices, in: Proceedings of 2008 IEEE Radio and Wireless Symposium, IEEE, Orlando, FL, USA, 2008, pp. 779–782. doi: 10.1109/RWS.2008.4463608.

[5] K. Shamaei, Z. M. Kassas, Receiver design and time of arrival estimation for opportunistic localization with 5G signals, IEEE Transactions on Wireless Communications 20(7) (2021) 4716–4731.

[6] H. B. Önen, M. Kartal, A time difference of arrival estimation with integration of generalized cross correlation samples for continuous wave signals on passive positioning systems, in: Proceedings of 2021 13th International Conference on Electrical and Electronics Engineering, IEEE, Bursa, Turkey, 2021, pp. 293-297. doi: 10.23919/ELECO54474.2021.9677772.

[7] G. Haywood-Alexander, et al., Informative Bayesian tools for damage localisation by decomposition of lamb wave signals, 2022. arXiv preprint arXiv:2205.12161.

[8] V. P. Natarajan, K. Thandapani, Adaptive time difference of time of arrival in wireless sensor network routing for enhancing quality of service, Instrumentation, Mesures, Métrologies, 20(6) (2021).

[9] O. Solomentsev, M. Zaliskyi, O. Kozhokhina, T. Herasymenko, Efficiency of data processing for UAV operation system, in: Proceedings of 4th International Conference Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD), IEEE, Kiev, Ukraine, 2017, pp. 27–31. doi: 10.1109/APUAVD.2017.8308769.

[10] A. Iatsyshyn, et al., Application of open and specialized geoinformation systems for computer modelling studying by students and PhD students, CEUR Workshop Proceedings 2732 (2020). 893–908.
[11] T. Hubanova, et al., Information technologies in improving crime prevention mechanisms in the border regions of southern Ukraine, Journal of Information Technology Management 13 (2021) 75–90. doi:10.22059/JITM.2021.80738.
[12] A. Dudnik, Y. Kravchenko, O. Trush, O. Leshchenko, N. Dakhno, V. Rakytskyi, Study of the Features of Ensuring Quality Indicators in Multiservice Networks of the Wi-Fi Standard, in: Proceedings of 3rd International Conference on Advanced Trends in Information Theory (ATIT), IEEE, Kyiv, Ukraine, 2021, pp. 93–98. doi: 10.1109/ATIT54053.2021.9678691.
[13] O. Pysarchuk, A. Gizun, A. Dudnik, V. Griga, T. Domkiv, S. Gnatyuk, Bifurcation Prediction Method for the Emergence and Development Dynamics of Information Conflicts in Cybernetic Space, CEUR Workshop Proceedings 2654 (2019) 692–709. URL: https://ceur-ws.org/Vol-2654/paper54.pdf.
[14] I. Bakhov, Y. Rudenko, A. Dudnik, N. Dehtiarova, S. Petrenko, Problems of Teaching Future Teachers of Humanities the Basics of Fuzzy Logic and Ways to Overcome Them. International Journal of Early Childhood Special Education (INT-JECSE) 13(2) (2021) 844–854. doi: 10.9756/INT-JECSE/V13I2.211127.
[15] I. Ostroumov, et al., Modelling and simulation of DME navigation global service volume, Advances in Space Research 69(8) (2021) 3495–3507. doi: 10.1016/j.asr.2021.06.027.
[16] Y. Daradkeh, L. Guryanova, S. Kavun, T. Klebanova, Forecasting the cyclical dynamics of the development territories: Conceptual approaches, models, experiments, European Journal of Scientific Research 74(1)(2012) 5–20.
[17] Y. Averyanova, et al., UAS cyber security hazards analysis and approach to qualitative assessment, In: S. Shukla, A. Unal, J. Varghese Kureethara, D.K. Mishra, D.S. Han (Eds.), Data science and security, volume 290 of Lecture Notes in Networks and Systems, Springer, Singapore, 2021, pp. 258–265. doi: 10.1007/978-981-16-4486-3_28.
[18] A. Bieliatynskyi, S. Yang, V. Pershakov, M. Shao, M. Ta, The use of fiber made from fly ash from power plants in China in road and airfield construction, Construction and Building Materials 323 (2022) 126537. doi: 10.1016/j.conbuildmat.2022.126537.
[19] R. Brumnik, T. Klebanova, L. Guryanova, S. Kavun, O. Trydid, Simulation of territorial development based on fiscal policy tools, Mathematical Problems in Engineering 2014 (2014) 843976.
[20] V. Kalashnikov, S. Dempe, B. Mordukhovich, S.V. Kavun, Bilevel optimal control, equilibrium, and combinatorial problems with applications to engineering, Mathematical Problems in Engineering 2017 (2017) 7190763.
[21] S. R. Ignatovich, A. Menou, M.V. Karuskevich, P.O. Maruschak, Fatigue damage and sensor development for aircraft structural health monitoring, Theoretical and Applied Fracture Mechanics 65 (2013) 23–27.
[22] A. Dudnik, O. Trush, V. Kvasnikov, T. Domkiv, Development of distributed multi-segment wireless networks for determining external situations, CEUR Workshop Proceedings 2845 (2021) 127–137. URL: https://ceur-ws.org/Vol-2845/Paper_13.pdf.