A Model of an IoT System Based on RFID Tags for Mine Defense under War Conditions and in the Post-War Period

Kateryna Kolesnikova [1] Myroslava Gladka [2], Mykola Kostikov [1,3] and Natalia Myronova [4]

[1] *International IT University, 34/1 Manas str, Almaty, 050040, Kazakhstan*
[2] *Taras Shevchenko National University of Kyiv, Volodymyrska Street, 60, Kyiv, 01601, Ukraine*
[3] *National University of Food Technologies, Volodymyrska Street, 68, Kyiv, 01601, Ukraine*
[4] *National University "Zaporizhzhia Polytechnic", Zhukovskogo, 64, Zaporizhzhya, 69063, Ukraine*

Abstract

Radio frequency identification (RFID) technology is widely used in various industries, including logistics, retail, healthcare, and agriculture. In recent years, RFID has also been explored for military and civilian applications, especially in wartime. RFID tags can be used to protect military and civilian population during war by providing real-time tracking of people, vehicles and equipment. The use of RFID tags in the military and defense complex is gaining great popularity [1, 2, 3], however, the use of RFID tags for mine security has not yet been fully explored. A separate important task under war conditions is the mine defense of territories where combat actions are taking place. The use of various mines to create blocking effects from the enemy ensures the security of territories in wartime and postwar times. The use of mines for the security of territories is known as "mine defense". This includes the placement of mines or explosive devices in a certain area or around important objects in order to protect these objects from possible threats.

The main aspects of using mines for the security of territories include: the creation of minefields (placement of mines or explosive devices in a certain area to create a minefield that can become an obstacle for potential invaders or enemies); creation of maps of minefields (designation of minefields to inform own troops and the civilian population about their presence and location, to avoid danger). It is important to note that the use of mines for the security of territories must comply with international norms and conventions regarding the prohibition of the use of anti-personnel mines, and must also comply with the principles of humanitarian law to protect the civilian population and minimize humanitarian consequences. The use of RFID tags on mines is a solution that fully ensures the implementation of these norms and conventions.

This article considers the use of RFID tags in wartime, the advantages of using RFID technology for the implementation of mine defense of territories, the rules for the protection of RFID tags used to ensure the safety of the military and civilian population.

Keywords [1]

IoT, RFID, identification, defense, war, military, civilian population, mine defense, security, safety

1. Introduction

Radio frequency identification (RFID) is a technology that uses radio waves for object identification and tracking. RFID tags are small electronic devices that can be attached to objects or implanted in living beings. Each of these tags contains a unique identifier that can be read by an RFIDreader. The use of RFID tags can have significant advantages for protecting the military and civilians during wartime. In this article, we will investigate the use of RFID tags for this purpose and provide some calculations and formulas to illustrate their effectiveness [1, 6]. RFID technology

Information Technology and Implementation (IT&I-2023), November 20–21, 2023, Kyiv, Ukraine
EMAIL: kkolesnikova@iitu.edu.kz (A. 1); gladkam@fit.knu.ua (A. 2); kostikov@knu.ua (A. 3); natalia.myronova@zp.edu.ua (A. 4)
ORCID 0000-0001-5233-2021 (A. 1); 0000-0002-9160-5982 (A. 2); 0000-0002-1569-8179 (A. 3); 0000-0001-7484-559X (A. 4)
© 2023 Copyright for this paper by its authors.
Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).
CEUR Workshop Proceedings (CEUR-WS.org)

CEUR-WS.org/Vol-3624/Short_1.pdf
CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

is widely implemented all over the world, and its impact on our daily life is very diverse and massive [7, 8]. The most relevant studies on the use of RFID for our country in today's conditions are security studies in wartime conditions [9]. RFID tags can be used to track the movement of military personnel, vehicles and equipment, and to monitor the location and condition of critical infrastructure such as power grids, water purification facilities and hospitals. This information can be used to help military commanders make informed decisions about where to deploy resources, how to allocate troops and supplies, and how to respond tothreats [10]. One of the key advantages of RFID tags is that they can be read remotely, without line of sight or physical contact [11]. This means they can be used in situations when traditional identification methods such as barcodes or QR codes may not be applicable. The relevance of this article is justified by the need to use reliable and simple mechanisms that can be easily implemented in a short time to ensure the security of territories and the population in the territories of combat actions in military and post-war times.

2. RFID Tags in Mine Defense and Combating Mine Threats

RFID tags can be important components in mine defense and countering mine threats [1, 12]. Here are some ways they can be used in this field.

1. Mine identification and tracking. RFID tags can be embedded in or placed next to mines. This allows you to create a system for identifying and tracking mines in real time. Operators can use special RFID readers to detect and identify mines, making it easier to destroy or defuse them.

2. Ensuring the safety of minesweepers. Specialists in demining can wear RFID tags on their uniforms or equipment. This allows you to track their location and, in case of an emergency, quickly determine their position for assistance.

3. Identification of safe areas. RFID tags can be placed in certain areas that have already been cleared of mines. This helps prevent the re-emergence of mines or indicates safe routes and areas.

4. Inventory of equipment and resources. RFID tags can be used to keep records and track various types of equipment and resources used in mining operations, helping to maintain inventory and control access to these resources.

5. Reporting and analytics. Data collected from RFID tags can be used to analyze and generate reports on mining operations performance and risks. It helps to plan future operations and make informed decisions.

RFID technology can improve the efficiency and safety of mine defense, as well as contribute to the protection of life and health of deminers and other workers in this field.

When using RFID tags on mines, you can create and visualize maps of minefields, which will ensure the relevance of data at any moment in time.

2.1. Algorithm for Designing Active RFID Tags for Use in IoT Mine Safety Systems

The calculation for designing active RFID tags for use in mine safety systems consists of several steps. Active RFID tags have their own power sources and can transmit signals over much longer distances than passive tags, making them efficient for use in such tasks [13, 14].

The general algorithm for creating an IoT tag system consists of the following steps (fig. 1):

1. Determination of needs and requirements. First, it is necessary to determine what requirements regarding active RFID tags exist in a specific case of mine safety. This may include reading range, battery life, power consumption, and other technical parameters.

2. Frequency (RFID band) choice. Defining a radio frequency that meets military needs. RFID tags can use different frequency bands such as LF (Low Frequency), HF (High Frequency), UHF (Ultra-High Frequency) or SHF (Super-High Frequency) depending on the distance and signal strength.

3. Power source. Determining the power source for active RFID tags. These are usually batteries or accumulators. This is done by calculating how long the tag can operate without replacing the power supply based on the needs and service life requirements, taking into account the conditions of use of these tags.

4. Energy-saving algorithms. Development of effective algorithms for the operation of active tags that allow them to enter the sleep mode and efficiently use energy in the active state. This includes the calculation of activity times and periods of sleep.

5. Calculation of the reading range. Empirical data and Friis equation or formulas for signal loss over distance are used to determine the reading range of active tags.

6. Antennas and communication units. Development of antennas and communication modules for tags that meet military requirements. They must be efficient in the selected frequency range.

7. Protection against exposure to dangerous factors. In mine safety, active RFID tags must be resistant to explosions and other dangerous conditions. Here it is necessary to distinguish whether it is required to keep a tag on a mine that has already detonated, or only to protect against explosions that are far from an active mine.

8. Testing and validation. Testing the created tags in real mine safety conditions to make sure they meet all requirements and function properly.

9. Production and deployment. After successful validation, production of active RFID tags can be started. After that, the tags are deployed in the mine environment.

10. Support and updates. The support process, including battery replacement and tag software updates, is as important to the quality of tag performance as development and implementation.

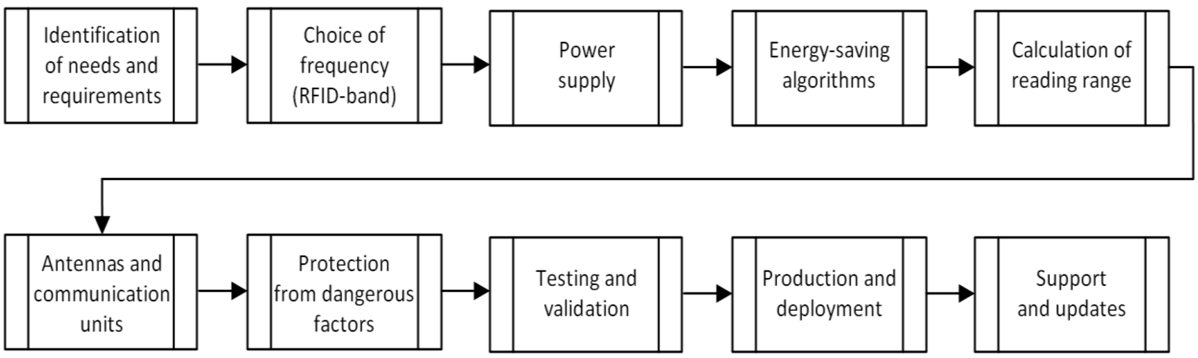

Figure 1: Algorithm for the development of a mine safety system based on RFID tags

This process of calculating and developing an IoT system based on active RFID tags in mine safety requires a lot of engineering work and specialized knowledge in the field of RFID technology, as well as military security. In practice, this can be challenging and resource-intensive, but it can significantly improve the safety and efficiency of operations in a mine environment.

2.2. Calculation of RFID Tags Range

The range (or radius) of active RFID tags on rough terrain can be determined using various factors such as signal strength, reader sensitivity, tag antenna characteristics, and environment conditions [1, 15]. Considering the key factors that influence the range of active RFID tags, you can use the Friis formula for calculations [16]. The Friis formula is used to determine signal loss over distance as a function of signal frequency, absorption loss, and signal propagation loss. The formula is as follows:

$$L = 20 \cdot \log_{10}(d) + 20 \cdot \log_{10}(f) + K \quad (1)$$

where:

L is the signal loss (dB); d is the distance between the tag and the reader (m); f is the signal frequency (Hz); K is correction factor that takes into account other signal losses (dB).

2.2.1. Reader Sensitivity and Tag Transmission Power

Reader sensitivity and tag transmission power are also important factors. The greater the transmission power of the tag and the sensitivity of the reader, the greater is the possible range. Usually, these values are indicated in the equipment specifications [1, 17].

2.2.2. Characteristics of the tag antenna

The size and characteristics of the antenna on the tag can also affect the range. A larger antenna usually provides a longer communication range [18].

2.2.3. Environmental Conditions and Obstacles

The environmental conditions such as humidity, surface type, metal obstructions, vegetation and other factors can also affect the signal range (fig. 2) [19, 20].

Please note that in real conditions, the range of active RFID tags can fluctuate significantly due to the influence of various factors. A key indicator for determining the range of RFID tags is the influence of terrain, as it is envisaged to install tags on mines located close to the surface of the earth, and not on a raised antenna above the earth's surface.

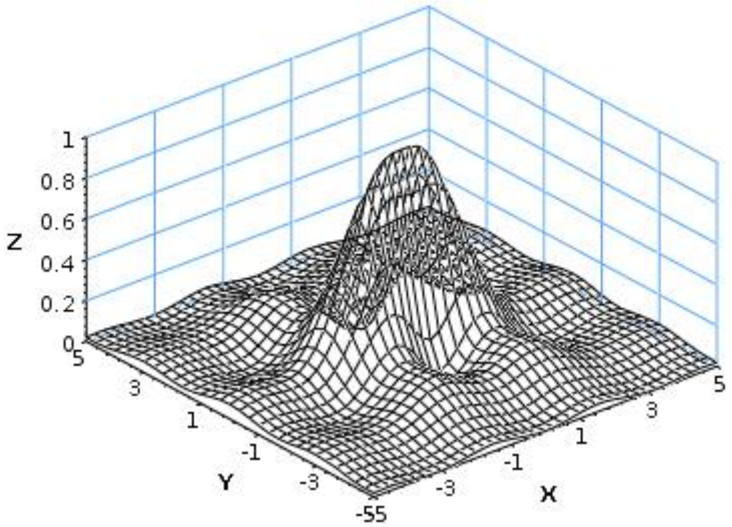

Figure 2: An example of a surface type for calculating the range of active RFID tags

2.3. The Effect of Terrain on the Range of RFID Tags

Determining the range of active RFID tags on cross-country terrain includes a number of factors that can be taken into account in calculations [21]. The main factors that affect the range of active RFID tags include:

- Transmitter power (T_x): The signal strength emitted by the active tag. Measured in decibel milliwatts (dBm).
- Receiver sensitivity (R_x): The sensitivity of the RFID reader to weak signals from tags. It is also measured in decibel milliwatts (dBm).
- Antenna height (H): The height of the location of the antenna on the tag and the height of the location of the antenna on the reader above ground level. It is measured in meters (m).
- Frequency (f): The operating frequency of the RFID system which is measured in gigahertz (GHz).
- Barriers (*path loss*): Signal loss caused by various obstacles such as trees, buildings, soil, etc.
- Location of antennas (d): The distance between the tag antenna and the reader antenna.
- Reader transmitter power (*Effective Isotropic Radiated Power – EIRP*): The reader's effective transmitter power, which includes the transmitter and amplifier power. It is measured in decibel milliwatts (dBm).

The range can be calculated using the formula for determining the communication in the radio frequency range (RF link budget) [22]:

$$L = EIRP - (T_x - R_x) + 20 \cdot \log_{10}(f) - 20 \cdot \log_{10}(d) - PL \tag{2}$$

where:

L is the communication range (m); $EIRP$ is the effective power of the reader transmitter (dBm); T_x is the tag transmitter power (dBm); R_x is the reader receiver sensitivity (dBm); f is the operating frequency of the RFID system (GHz); d is the distance between the tag antenna and the reader antenna (m); PL is the signal loss caused by barriers and other factors (dB). This formula allows you to calculate the approximate range of active RFID tags in specific terrain conditions. These parameters can be measured or defined in the RFID equipment specification data [23].

2.3.1. Peculiarities of Measuring the Distance to RFID Tags on Cross-Country Terrain

The location of the tags on the earth surface is less than or equal to L which is the distance of the wireless transmission of the equipment and devices fixing the position location. When installing the tag directly on the mine itself, tag detection substations can be placed above the surface, both on moving (drones) and non-moving objects. This will allow to quickly determine maps of tag locations on the basis of data exchange [24, 25]. A feature of such measurements is the establishment of calibration points [26] and the use of two or more substations (S_1, S_2, S_3) for tag readers. Then the process of detecting the tag (M) on the mine is as follows:

1. Measuring the calibration point at a distance $d(S_1, M)$ from substation S_1, $d(S_2, M)$ from S_2, $d(S_3, M)$ from S_3.
2. In case of absence of a signal from one of the calibration points, it is rational to use an additional substation or perform calculations based on signal data from at least two substations. As the accuracy improves, the number of reader substations increases (S_4, S_5, …).
3. Record the absolute strength of the tag detection signal received by substations S_1, S_2, S_3 during signal transmission as $P(S_1, M)$, $P(S_2, M)$, $P(S_3, M)$.
4. According to the received data, generate data for the table of distances to the substation that generates detection data corresponding to the absolute signal strength.
5. Calculate the absolute signal strength of each substation and the absolute signal strength and the ratio of two remote substations, the generation from Table 1 according to the relative signal intensity.

Table 1

Indicators of distances between tags and substations

Substation	Distance	Absolute signal strength
S_1	$d(S_1, M)$	$P(S_1, M)$
S_2	$d(S_2, M)$	$P(S_2, M)$
S_3	$d(S_3, M)$	$P(S_3, M)$

The process of calculating the position of the tag on the mine is as follows:

1. Synchronization of equipment on site, data exchange, transmission of device numbering information, location and time stamp information detection signal to neighboring substations with readers.
2. Each substation receives a tag detection signal, data on the intensity of this signal, numbering of the location determination device, information about the time stamp and its own ground location determination (for mobile or stationary receivers).
3. After the reader receives data about the location of the tag placed on the mine, we receive the information transmitted in the reverse direction. Different substations can be distinguished according to the numbering of devices, location determination and time stamp. It is necessary to clearly distinguish individual tags placed on individual mines, since the reader range can see more than one such tag within its range. The absolute signal power P of the same detection signal received by the location equipment is $P(S_1, M)$, $P(S_2, M)$, $P(S_3, M)$.
4. The IoT positioning system analyzes according to the numbering of each substation and the maximal absolute signal strength, how far away is the tag M in the maximum absolute degree of the signal to the substations S_1, S_2 and S_3, and if the two substations S_1, S_2 are equidistant from the tag,

then the alternative substation S_3 can determine correction angles to determine the distance to a tag located between two substations placed in the middle.

5. The absolute signal power of the tag M to two substations S_1, S_3 is the absolute signal power of each substation, which is obtained by calculating the shortest distance from the absolute signal powers.

6. According to the table of distances (Table 1), which corresponds to the relative intensity of the tag signal by the relative intensity of the substation signal, we will obtain the location location for each tag at a distance (S_1, M), (S_2, M), (S_3, M). If one of the substations did not receive a distance result, the calculations are based on the direct values of the two relative signals for $d(S_1)$ and $d(S_2)$.

7. We calculate the linear interpolation of the angle value. If the relative signal intensity of the current substation S_1 to the tag M is equal to M_x, then the two closest relative coordinate points to the distance from the substation to the tag are M_1, M_2. Accordingly, $M_1 < M_x < M_2$.

8. The distance corresponding to the distance between the tag and the substation S_1 is dm_1, dm_2 respectively. Then we get:

$$d(S_1, M) = \frac{(dm_1 - dm_2)\cdot(M_2 - M_1)}{M_2 - M_1} + d_2 \tag{3}$$

9. The distances $d(S_1, M)$, $d(S_2, M)$, $d(S_3, M)$ distances are calculated similarly. They give us 3 values of distance between the tag and each substation with readers. We get the corresponding coordinate values ($x_{S1,M}$, $y_{S1,M}$, $z_{S1,M}$),

$$(x_{S_2,M}, y_{S_2,M}, z_{S_2,M}), (x_{S_3,M}, y_{S_3,M}, z_{S_3,M}) \tag{4}$$

10. To calculate the distances determined by the line with two points, we will use the segment distance formula to achieve a linear equation in the form of two points. The group of equations for all determined location points will have the following form:

$$(x_{S_1,M}, y_{S_1,M}, z_{S_1,M}) = \begin{cases} d(S_1, M) = \sqrt{(x_{S_1,M} - x_{S_1})^2 + (y_{S_1,M} - y_{S_1})^2 + (z_{S_1,M} - z_{S_1})^2} \\ \dfrac{x_{S_1,M} - x_{S_1}}{x_{S2} - x_{S_1}} = \dfrac{y_{S_1,M} - y_{S_1}}{y_{S2} - y_{S_1}} = \dfrac{z_{S_1,M} - z_{S_1}}{z_{S2} - z_{S_1}} \\ \min(|x_{S_1}|, |x_{S_2}|) \le |x_{S_1,M}| \le \max(|x_{S_1}|, |x_{S_2}|) \\ \min(|y_{S_1}|, |y_{S_2}|) \le |y_{S_1,M}| \le \max(|y_{S_1}|, |y_{S_2}|) \\ \min(|z_{S_1}|, |z_{S_2}|) \le |z_{S_1,M}| \le \max(|z_{S_1}|, |z_{S_2}|) \end{cases} \tag{5}$$

11. The latter three formulas the latter three formulas consist in the fact that a group of equations solves the qualification of the ratio of the location of the tag x, in accordance with the location of the points $x_{S1,M}$, $y_{S1,M}$, $z_{S1,M}$, relative to the location of the substation S_1.

12. The coordinates ($x_{S2,M}$, $y_{S2,M}$, $z_{S2,M}$), ($x_{S3,M}$, $y_{S3,M}$, $z_{S3,M}$) of the tag location relatively to other reader substations are calculated similarly.

13. The found results ($x_{S2,M}$, $y_{S2,M}$, $z_{S2,M}$) and ($x_{S3,M}$, $y_{S3,M}$, $z_{S3,M}$) determine the distance d, $d(S_2, M)$ and $d(S_3, M)$.

14. Calculating ($x_{S1,M}$, $y_{S1,M}$, $z_{S1,M}$), ($x_{S2,M}$, $y_{S2,M}$, $z_{S2,M}$), ($x_{S3,M}$, $y_{S3,M}$, $z_{S3,M}$) allows us to find each reference axis value and gives the coordinates of the tag location point on the mine:

$$(\overline{x_M}, \overline{y_M}, \overline{z_M}) = \begin{cases} \overline{x_M} = \dfrac{(x_{S_1,M} + x_{S_2,M} + x_{S_3,M})}{3} \\ \overline{y_M} = \dfrac{(y_{S_1,M} + y_{S_2,M} + y_{S_3,M})}{3} \\ \overline{z_M} = \dfrac{(z_{S_1,M} + z_{S_2,M} + z_{S_3,M})}{3} \end{cases} \tag{6}$$

When calculating all three positions of the distance between the tag and the reader, we get the positional physical location of the tag to determine the location of the mine. It is rational to use additional substation readers, and in the case of weak signals to ignore the location data of substations that have the maximal distance to the tag, taking into account the arithmetic mean values for the group of each reference axis with the value of the residual location point [27, 28]. Therefore, the coordinate points become the physical location of the equipment for determining the location.

2.4. Security of RFID-Based IoT Systems

Military IoT systems based on RFID must be especially reliable and secure, as they are used in high-risk and conflict conditions [29]. Key aspects of the security system for the use of RFID in military applications include:

- Data encryption: It is important to use encryption to protect data transmitted between RFID tags and readers. Encrypted data makes it difficult to intercept and have an unauthorized access to information;
- Authentication: To ensure the security of an RFID network, it is important to use authentication procedures to ensure that only authorized users have access to the system. This may include the use of passwords or other methods of identification;
- Physical security: The use of integrated tags and readers must be subject to physical control and protection to prevent physical break-in or theft of the equipment;
- Protection against interference: In military operations, there can be a lot of electromagnetic and radio frequency interference. RFID systems must be perfectly protected against such interference to ensure reliable operation;
- Audit and monitoring: It is important to have an auditing and monitoring system that keeps logs of actions and events in the system. This helps to identify potential threats and attacks and take appropriate action;
- Protection against cloning: RFID tags must have protection against cloning to prevent the creation of counterfeit tags that can be used for unauthorized access;
- Tactical Security: In military operations, RFID systems must be adapted to tactical needs, including the ability to operate under conditions of an electronic warfare and provide protection from adversary detection;
- Physical security of tags: Military tags must be additionally protected against physical damage or destruction;
- Protection against interception of communications: Communication between readers and tags must be protected from interception or intrusion;
- Anti-spoofing: Providing protection against spoofing attacks, when an attacker can send false signals to the system.

These measures will ensure the reliable and secure functionality of the RFID system in military environments where confidentiality and reliability are very important [29]. It is also important to remember that security standards and technology are constantly evolving, and systems must be updated and modernized to meet modern requirements.

3. Conclusions

The development and application of RFID-based IoT devices has a great potential to improve the security of military and civilian population in wartime. Using this technology can help track resources, monitor infrastructure and ensure the safety of facilities and personnel in real time, which solves important tasks in the context of military conflicts.

The prospect of using RFID-based IoT devices in military operations promises many opportunities to improve security, efficiency and command. The development and improvement of this technology requires research and innovation in many directions.

Using the technology based on RFID tags for creation of an IoT mine safety system allows monitoring the condition of mine fortifications in the territory without saving mine maps or using barrage mines for fortifications and protection of territories [31]. The article emphasizes that the exact range for the identification of a mine tag will depend on the specific conditions of the area, and it directly depends on the terrain relief. Therefore, when calculating by the theoretical formulas, a number of factors must be taken into account due to signal loss in terrain conditions. The actual range should be determined by on-site measurements using RFID equipment. The use of RFID tags for the positioning of mines in the territories of combat actions, or in territories that need protection from invasions, is an urgent task for the safety of the military and the population staying in these territories

In military applications, information security is crucial. IoT systems open up new opportunities for collecting and sharing information, but at the same time they are becoming more vulnerable to cyberattacks [32, 33]. Protection of IoT information systems includes data encryption, authentication and access control, as well as network reliability and monitoring systems.

4. References

[1] M. Gladka, A. Kuchansky, M. Kostikov, R. Lisnevskyi, A Model of the Application of IoT Devices Based on RFID to Ensure the Safety of the Military and Civilian Population under War Conditions, in: Selected Papers of the IX International Scientific Conference “Information Technology and Implementation" (IT&I-2022). Workshop Proceedings, Kyiv, Ukraine, November 30 – December 02, 2022. https://ceur-ws.org/Vol-3347.

[2] M. Deng, P. Feng, Research Status on RFID System Authentication Protocol, in: AICS 2019: Proceedings of the 2019 International Conference on Artificial Intelligence and Computer Science, July 2019, pp. 432–438. URL: https://doi.org/10.1145/3349341.3349446.

[3] D. Lj. Bogićević, I. A. Tot, R. I. Prodanović, B. J. Todorović. Identification of soldiers and weapons in military armory based on comparison image processing and RFID tag, in: Vojnotehnički glasnik, January 2021, vol. 69(1), pp. 179–195. DOI: 10.5937/vojtehg69-28114.

[4] C. Hema, S. Sankar, Collision Mitigation Algorithm for Tracking of RFID Based Assets in Defence, in: EAI Endorsed Transactions on Energy Web, vol. 8, no. 36. DOI: https://doi.org/10.4108/eai.9-3-2021.168963.

[5] M. Chmielewski, M. Kukiełka, Applications of RFID technology in dismounted soldier solution systems – study of mCOP system capabilities, in: MATEC Web of Conferences, vol. 76, p. 04014. DOI: https://doi.org/10.1051/matecconf/20167604014.

[6] A. J. Bamidele, S. N. Sur, M. Aderinto, T. Gaber, RFID-Based Student Identification Card Attendance Monitoring System, in: Advances in Communication, Devices and Networking, July 2023. DOI: 10.1007/978-981-99-1983-3_4.

[7] S. Li, J. K. Visich, B. M. Khumawala, C. Zhang, Radio frequency identification technology: applications, technical challenges and strategies, in: Sensor Review, 2006, vol. 26, pp. 193–202. DOI: 10.1108/02602280610675474.

[8] D. C. Wyld, RFID: The right frequency for government, Washington DC: IBM Center for the Business of Government, IBM Center; 2005.

[9] RFID Applications for National Defense, National defense made more secure with military-grade RFID solutions. URL: https://www.hidglobal.com/solutions/rfid-applications-national-defense

[10] V. Nikiforenko, A. Vikhtiuk, Main threats to the national security of Ukraine on the state border and trends in their development, in: Collection of scientific works of the National Academy of the State Border Guard Service of Ukraine, series: Military and Technical Sciences, 2021, vol. 85, no. 2–3, pp. 202–221.

[11] F. Babaeian, N. C. Karmakar, Development of cross-polar orientation-insensitive chipless RFID tags, in: IEEE Transactions on Antennas and Propagation, 2020, vol. 68, no. 7, pp. 5159-5170. DOI: 10.1109/TAP.2020.2975639

[12] S. Ajami, A. Rajabzadeh, Radio Frequency Identification (RFID) technology and patient safety, in: J Res Med Sci., 2013 Sep, 18(9):809–13. PMID: 24381626. PMCID: PMC3872592.

[13] A. N. Nambiar, RFID technology: A review of its applications, in: Proceeding of the World Congress on Engineering and Computer Science, Oct. 20–22, San Francisco, USA, 2009.

[14] B. Shrestha, A. Elsherbeni, L. Ukkonen, UHF RFID reader antenna for near-field and far-field operations, in: IEEE Antennas and Wireless Propagation Letters, 2011, vol. 10, pp. 1274–1277.

[15] N. C. Karmakar, Handbook of Smart Antennas for RFID Systems, John Wiley and Sons, NJ, 2010, 218 p.

[16] J. A. Shaw, Radiometry and the Friis transmission equation, in: American Journal of Physics, 2013, vol. 81, no. 33, pp. 33–37. DOI:10.1119/1.4755780.
[17] X. Z. Lai, Z. M. Xie, Q. Q. Xie, J. W. Chao, A Srr-based near field RFID antenna, in: Progress in Electromagnetics Research C, 2012, vol. 33, pp. 133–144.
[18] R. Abdulghafor et al., Recent advances in passive UHF-RFID tag antenna design for improved read range in product packaging applications: A comprehensive review, in: IEEE Access, 2021, vol. 9, pp. 63611–63635. DOI: 10.1109/access.2021.3074339.
[19] G. Baldini, F. Oliveri, M. Braun, H. Seuschek, E. Hess, Securing disaster supply chains with cryptography enhanced RFID, in: Disaster Prevention and Management: An International Journal, 2012, vol. 21, iss. 1, pp. 51–70.
[20] A. Tzitzis, S. Megalou, S. Siachalou, T. G. Emmanouil, A. Filotheou, T. V. Yioultsis, A. G. Dimitriou, Trajectory planning of a moving robot empowers 3D localization of RFID tags with a single antenna, in: IEEE Journal of Radio Frequency Identification, 2020, vol. 4, no. 4, pp. 283–299.
[21] C. F. Huang, Y. F. Huang, Design of RFID reader antenna for exclusively reading single one in tag assembling production, in: Int. J. Antennas Propag., 2012, vol. 2012, Article ID 162684, 5 p.
[22] G. Z. González, Radio Frequency Identification (RFID) Tags and Reader Antennas Based on Conjugate Matching and Metamaterial Concepts: Ph.D. thesis, Bellaterra (Cerdanyola del Vallès), July 2013, 130 p.
[23] J. Landt, The history of RFID, in: IEEE Potentials, New York, NY, 2005, 24(4):8–11. DOI: 10.1109/MP.2005.1549751.
[24] G. Zamora, S. Zuffanelli, F. Paredes, F. J. Herraiz-Martinez, F. Martín, J. Bonache, Fundamental mode leaky-wave antenna (LWA) using slot line and split-ring-resonator (SRR) based metamaterial, in: IEEE Antennas and Wireless Propagation Letters, May 2013, vol. 12, pp. 1424–1427. DOI: 10.1109/LAWP.2013.2287525.
[25] M. Gladka, A. Kuchansky, R. Lisnevskyi, Teams formation for IT projects implementation on the basis of the model of limited rationality, in: Management of Development of Complex Systems, 2021, vol. 48, pp. 17–23. DOI: 10.32347/2412-9933.2021.48.17-23
[26] S. Barone, P. Neri, A. Paoli, A. V. Razionale, 3D acquisition and stereo-camera calibration by active devices: A unique structured light encoding framework, in: Optics and Lasers in Engineering, 2020, vol. 127, pp. 105989.
[27] C. Chen, B. Hu, Y. Li, Easy-to-use spatial random-forest-based downscaling-calibration method for producing precipitation data with high resolution and high accuracy, in: Hydrology and Earth System Sciences, 2021, vol. 25, no. 11, pp. 5667–5682.
[28] E. Bergeret, J. Gaubert, P. Pannier, J. M. Gaultier, Modeling an design of CMOS UHF voltage multiplier for RFID in a EEPROM compatible process, in: IEEE Trans. Circuits and Systems, Oct. 2007, vol. 54, no. 10, pp. 833–837.
[29] M. Gladka, O. Kravchenko, Y. Hladkyi, S. Borashova, Qualification and appointment of staff for project work in implementing IT systems under conditions of uncertainty, in: 2021 IEEE International Conference on Smart Information Systems and Technologies. Astana IT University. Nur-Sultan, Kazakhstan, April 28–30, 2021. DOI: 10.1109/SIST50301.2021.9465897.
[30] V. Kumar, R. Kumar, A. A. Khan, V. Kumar, Y. C. Chen, C. C. Chang, RAFI: robust authentication framework for IoT-based RFID infrastructure, in: Sensors, 2022, vol. 22, no. 9, p. 3110. doi.org/10.3390/s22093110.
[31] J. Zhou, M. Koopialipoor, B. R. Murlidhar, S. A. Fatemi, M. M. Tahir, D. J. Armaghani, C. Li, Use of intelligent methods to design effective pattern parameters of mine blasting to minimize flyrock distance, in: Natural Resources Research, 2020, vol. 29, pp. 625–639.
[32] Y. Hladkyi, M. Gladka, M. Kostikov, R. Lisnevskyi, An IoT Solution: A Fitness Trainer, in: Information Technology and Implementation (IT&I-2021), December 01–03, 2021, Kyiv, Ukraine: CEUR Workshop Proceedings, 2021, 3179, pp. 215–226.
[33] M. Gladka, O. Kravchenko, Y. Hladkyi, S. Borashova, Qualification and Appointment of Staff for Project Work in Implementing IT Systems under Conditions of Uncertainty, in: SIST 2021 – 2021 IEEE International Conference on Smart Information Systems and Technologies, 2021, ISBN:978-1-7281-7470-9, https://doi.org/10.1109/SIST50301.2021.9465897.