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EVALUATING ENERGY EFFICIENCY OF IDENTIFICATION SYSTEMS

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Abstract

The quest for energy efficiency has become increasingly paramount in today's technology-driven world, where the optimization of energy consumption is essential for sustainable development. Identification systems, encompassing a wide array of technologies such as RFID (Radio Frequency Identification), biometrics, and barcode systems, play a crucial role in various sectors including logistics, manufacturing, and security. This paper delves into the energy efficiency aspects of identification systems, exploring how these systems can be optimized to minimize energy consumption while maintaining operational effectiveness.

Furthermore, the abstract discusses the challenges and opportunities associated with implementing energy-efficient identification systems in different contexts. It addresses issues such as compatibility with existing infrastructure, scalability, and the trade-offs between energy efficiency and system performance. The paper concludes by offering insights into future research directions and practical implications for stakeholders interested in advancing energy efficiency in identification systems.

Keywords: *Energy efficiency, Identification Systems, RFID, Video Camera, Environmental impact.*

INTRODUCTION

In today's digital era, one of the prominent challenges lies in ensuring the energy efficiency of identification systems. These systems encompass various technologies and processes utilized for verifying the identity of individuals or objects, serving purposes such as security, access control, and authentication. They include a range of systems like biometric identification, video surveillance, RFID, smart cards, and barcode systems e.c.

Effective identification and tracking of objects, whether in closed or open spaces, are crucial for operational performance, data management, and security. However, as the number of objects requiring identification increases, the expansion and management of identification infrastructure become progressively challenging. Traditional identification methods are no longer equipped to handle large volumes of objects and must be deployed rapidly at scale.

MAIN PART

Despite the utilization of low-power components in identification systems designed to minimize energy consumption, achieving energy efficiency remains a significant challenge. This study focuses on comparing two common identification systems: RFID technology for object identification and video camera identification systems.

RFID technology offers several advantages:

- RFID provides standardized and unique identification For each marked item;
- RFID tags can support cryptographic protocols;
- RFID systems are highly scalable, allowing organizations to effectively manage a large number of devices;

- RFID can be integrated with other sensors and with technologies that provide uniform identification of objects approach.
- RFID reduces the likelihood of human errors in identification in processes;

To identify using RFID, we employ active tags with extended reading range and tamper detection features. The system incorporates an intuitive dashboard for real-time monitoring and situational description.

Efforts have been made to enhance energy efficiency through RFID technology. One approach involves optimizing RFID tag design to reduce power consumption during operation. This entails designing low-power integrated circuits, utilizing energy-harvesting methods for tag power, and implementing sleep modes to minimize power usage during idle periods. Furthermore, adherence to standards like the EPC Gen2 standard for RFID communication aids in simplifying deployments and ensuring interoperability while minimizing energy consumption.

The second system under comparison is a video camera identification system, where monitoring energy efficiency is crucial for minimizing energy usage and environmental impact while maintaining surveillance capabilities [1].

Similarly, various strategies can enhance the energy efficiency of video surveillance cameras, including implementing power management features such as sleep modes, motion detection triggers, and scheduled recording to reduce energy consumption during idle periods. Employing energy-efficient components and adjusting recording parameters like resolution and frame rate can further optimize energy usage, while integration with smart lighting systems and solar panels enables intelligent control of lighting conditions based on activity levels, thereby reducing the need for constant illumination and conserving energy. Implementing power management features of video cameras, such as sleep modes, motion detection triggers, and scheduled recording, significantly reduces energy consumption during periods of inactivity.

- The utilization of energy-efficient components and hardware, including low-power processors, sensors, and imaging modules, aids in minimizing power consumption without compromising performance.
- Adjusting recording parameters such as resolution, frame rate, and compression algorithms can optimize video quality, thereby reducing the amount of data transmitted and stored, leading to lower energy consumption.
- Integrating surveillance video cameras with smart lighting systems and solar panels enables intelligent control of lighting conditions based on environmental factors and activity levels, thus reducing the need for constant lighting and conserving energy.

It is important to note that the implementation of analytics and artificial intelligence (AI) algorithms enhances the effectiveness of monitoring systems by reducing false alarms and optimizing resource allocation for both systems. Below, the table1 presents a comparative analysis of energy consumption resulting from our research [4].

Table I. Comparative analysis of energy consumption

RFID	Video Camera
Passive RFID tags do not require power The source and power are taken from the radio frequency of the RFID reader from signals during communication. It's them It makes it extremely energy efficient	video cameras Need a continuous power source that can vary Depending on factors such as Resolution, frame rate, and recording parameters.

RFID	**Video Camera**
RFID systems can be deployed in different environments, including In remote areas, infrastructure, or uninterrupted power Without the need for sources, which they Make it suitable for energy-limited applications	Video cameras require a stable power source or battery pack, which limits the flexibility of their placement, especially in outdoor or remote places
RFID systems transmit small amounts of data wirelessly Short distances that require minimum energy for communication. Passive RFID tags have limitations in range and usually consume Very low energy data during transmission	Video cameras record and transmit A large amount of data Constantly, especially high resolution and in real-time In monitoring applications. Video Data transmission over long distances Or it can be used wirelessly for a significant amount of energy
Passive RFID tags can permanently to work for maintenance or battery replacement without needing what suits them Makes long-lasting and low For technical applications	Camcorders require periodic maintenance Maintenance, including battery replacement, cleaning, and software Providing updates can increase over time their energy consumption and operation expenses
Passive RFID tags have a minimal environmental impact because they do not contain batteries or hazardous materials which makes them environmentally friendly and sustainable	Camcorders contain electronic components, batteries, and materials that may have an impact on the environment Impact, especially during production, destruction, or recycling.

In the presented article, our focus is on the energy efficiency aspects of RFID identification. Active RFID tags, which include a battery, offer advantages such as extended reading range, faster data transfer, and enhanced sensor capabilities. However, a drawback is that the battery life is finite and depends on factors such as the frequency of tag reads and the transmitted data volume. Ongoing research aims to enhance the battery performance of active RFID tags through methods like low-power chip design and optimized communication protocols [5-6-7-8].

Considering additional factors, such as the number of tags involved, is crucial as it can significantly impact overall energy consumption. Therefore, experimental research has been conducted to investigate the effects of various factors on identification efficiency. These factors include the distance between the reader and the tag, the size of obstacles, the quantity of tags to be read, and the reader's performance. Position concerning the surveillance object.

We conducted a three-factor experiment (Table2):

A factor - the distance between the reader and the tag

B factor - weight/volume of the obstacle

C factor - the number of readable tags Experiment plan

Table II. Factor experiment

		1m	2m	3m
		A1	**A2**	**A3**
Without obstruction	**B1**	C1	C2	C3
Metal 1	**B2**	C2	C3	C1
Metal 2	**B3**	C3	C2	C2

C1	**C2**	**C3**
1	**20**	**40**

The experiment was carried out according to the plan and the time of reading the tags was fixed, according to the factorial experiment we calculated the variances related to the influence of the factors $S_A^2 = 648.21$, $S_B^2 = 3303.3$, $S_C^2 = 4214.3$ Variance related to experiment error $S_0^2 = 38.9$, based on which we obtained the Fisher's criterion Values $F_1 = 16.67$; $F_2 = 84.91$; $F_3 = 108.324$ which we compared to Fisher's critical value $F_c = 9$. As we can see, all values are allowed It is more than the critical limit, which confirms the significant influence of all three factors on the identification process. To the extent that the factors have a substantial influence, calculate the influence effects $\sigma_A^2 = 203.103$; $\sigma_B^2 = 1088.29$; $\sigma_C^2 = 1391.82$;

The experiment showed us that the distance of the object from the reader, as well as them There are various types of obstacles and a multitude of objects in between Affects tag read time. But especially among them

2 = 1391.82;

The presence of metal barriers of different sizes/shapes and the number of tags to be read per unit of time can be distinguished, which significantly changes the reading time [2].

The experiment also showed us that effective identification is influenced not only by the above factors but also by the reader's attitude toward the surveillance objects (more precisely, towards the tag). Research has shown that if the reader is tilted toward the starting object, the so-called reading is significantly reduced. Dark spots and the more tags the system can read, the tilt angle also depends on the distance between the reader and the tag. Taking into account the results of our research, we have developed a system focused on the identification of objects using RFID, however, as in the modern situation, only identification is not enough for efficient management of processes, we have taken into account monitoring of environmental characteristics in the system architecture, in many cases these parameters affect the storage and life cycle of the object while taking into account security issues and receiving relevant notifications in real-time mode. The structural scheme of the developed system is presented in the figure I.

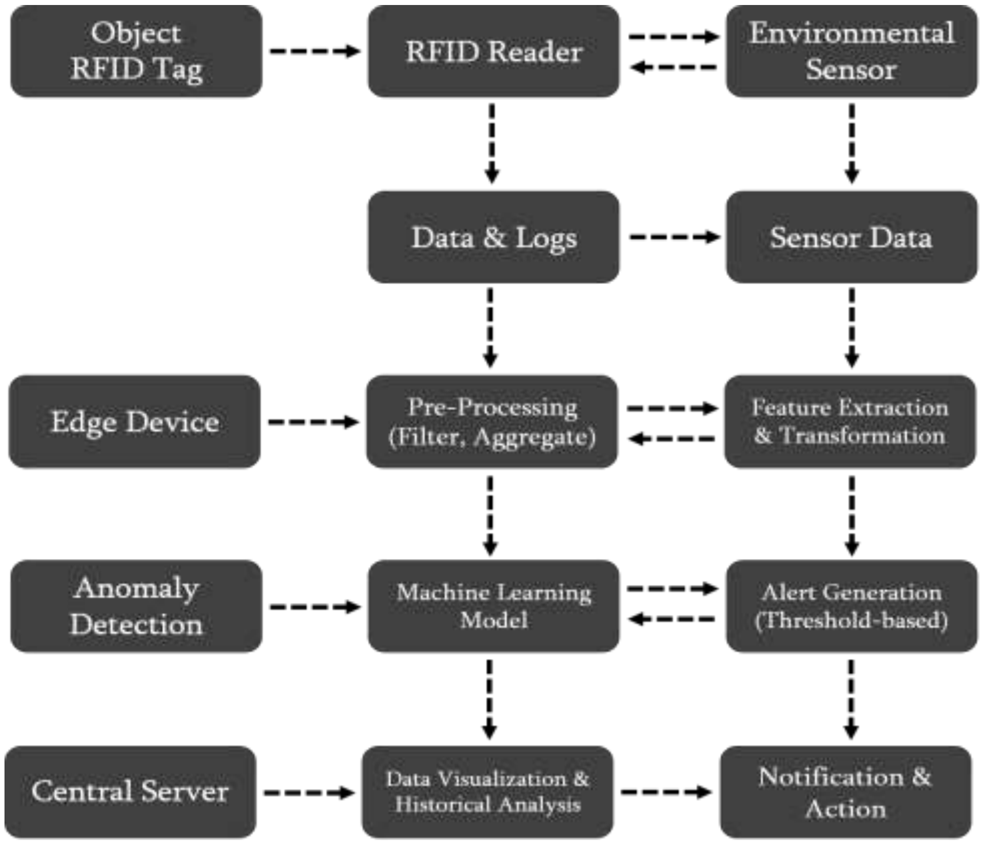

Figure I. The structural scheme of the developed system

The system includes **temperature and humidity monitoring**: to detect extreme temperature or humidity changes that may damage the object or create a risk of corrosion; **Motion detection**: to detect unauthorized movement or object tampering;

Pressure sensors: to detect potential disturbances or structural changes in the warehouse; Air quality monitoring sensors: to detect harmful substances or changes in air composition; **Vibration sensors**: to detect a potential attempt to move or remove an object without authorization; **Acoustic sensors**: to detect suspicious sounds such as breaking glass or forced entry attempts.

To ensure safety, sensors are positioned to cover all critical areas to prevent arious manipulations. Secure communication between the sensors and the central system to protect sensitive data through data encryption. At a different stage of the experiment, we discussed the use of different types of sensors for redundancy and increased reliability. We discussed the difficulty of integrating various sensors with an existing RFID system. For basic temperature and humidity monitoring, we use cost-effective, commercially available humidity and temperature sensors. For advanced motion detection, we use passive infrared (PIR) sensors or optional radar-based sensors for wider coverage and better sensitivity. To monitor vibration, acoustics, pressure, and air quality, we use specialized sensors designed for these specific purposes.

Deep learning for real-time RFID monitoring in research facility The application represents a promising solution for security and management to improve processes. RFID readers will be installed throughout to guide the process In the warehouse to continuously collect data with RFID tags Regarding the movement and location of marked objects. Data It is being developed in advance for input into a deep learning model. Processing involves noise filtering and proper data formatting.

A CNN model capable of RFID data is developed for Processing of spatial and temporal patterns. A CNN can analyze the detection sequence of RFID tags to identify patterns that Relate to the movement and storage of objects. RFID data to analyze product movement and Storage spatial and temporal patterns building a CNN model for identification involves several key steps

Given the nature of the task, where we are dealing with sequential with data (the detection sequence of the RFID tags), we will use this purpose-built 1D CNN architecture. for model development, we used a structured approach:

1. Data preprocessing
2. Model architecture
3. Model design
4. Model

construction and training Loss function: We choose an appropriate loss function such as Categorical cross-entropy of the multi-class nature of the problem considering.

Optimizer: We use the Adam optimizer for efficient gradients for descent [3].

Training: We prepare a model on labeled RFID data

By monitoring the environment and detecting anomalies, an RFID monitoring system can significantly enhance security, streamline operations, and provide warehouses with valuable real-time information, making them safer, more efficient, and more data-driven.

Comparative analysis of the existing and proposed system (Table 3):

Table III. Comparative analysis of the existing and proposed system

Function	Existing systems	Proposed system
Frequency of tracking	Mechanical inspections, periodic	Real-time, continuous
Exposure to danger	Reactive, limited coverage	Proactive, comprehensive
Disruption Detection	Based on the perimeter	Susceptible to unauthorized access attempts
Operational efficiency	Mechanical processes	Automated, data-driven
Scalability	Limited	Easily scalable according to requirements

An RFID monitoring simulation was carried out for the experiment:

Technical characteristics:

STM32F103C8 series ARM microcontroller was used for the work Frequency - up to 72 megahertz, flash memory size - 64 kilobytes, RAM Memory size - 20 kilobytes, working voltage - 3.3V, input voltage - 5V, number of input/output ports - 37, used for communication Interfaces - UART - 38400bps speed, I2C - High Speed, 400 kHz Used peripheral - Timer1 - 8 megahertz speed, additionally has been installed 16x2 LCD display with I2C interface. Factorial The plan of experiments is given in the following figure

A factor - represents the distance between the tag and the reader, B factor - the angle of inclination of the reader

TABLE IV. plan of experiments

	A1	A2	A3	A4	∑
B1	Y11	Y21	Y31	Y41	Y_1’
B2	Y12	Y22	Y32	Y42	Y2’
B3	Y13	Y23	Y33	Y43	Y3’
B4	Y14	Y24	Y34	Y44	Y4’
∑	Y1	Y_2	Y_3	Y_4	

The experiment was conducted to read a single tag as well as large tags to read the quantity. The experiment was conducted with various obstacles and Also in free space.

The results of the experiment are given in the tables:

Table V. Reader and tag direct to each other Placed in view mode

N	Distanc		
	1m	1.5 m	2 m
1	1,314	2,7	3,23
2	1,078	1,86	2,99
3	1,068	1,67	2,8
4	1,280	1,66	2,62

Table VI. Reader tag 450 is inclined towards angle

N	Distanc		
	1m	1.5 m	2 m
1	0,99	2,8	17,4
2	1,2	1,4	29,3
3	0,93	1,78	26,9
4	1,13	4,38	15,6

In addition to the above experiments, we planned experiment 27 To read the tag, we changed the distance and the reader in the same way tilt, we conducted tests both in free space and in different ones with obstacles.

The results of the conducted experiment are visualized in the following figures:

Figure II. Result of Experiment

Experiment 27 was devised to further investigate tag reading capabilities. Varied factors, including distance adjustments and reader tilt, were manipulated to assess performance under diverse conditions. Tests were conducted in both unobstructed environments and those with obstacles present. The results of Experiment 27 have been visually represented in the accompanying figures, providing valuable insights into the efficacy of tag reading across different scenarios.

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CONCLUSION

This study highlights the significance of energy efficiency in identification systems, focusing on RFID technology and video camera identification systems. Through comparative analysis and experimental research, we identified key factors influencing system efficiency and proposed strategies for optimization. The development of real-time monitoring systems integrating environmental sensors and deep learning techniques further underscores the potential for enhancing security and operational efficiency. Overall, addressing energy efficiency challenges is crucial for advancing sustainable and effective identification solutions in the digital age.

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