engineering proceedings

Proceeding Paper

Modeling Energy Losses in a Wireless Sensor Network for Monitoring Environmental Parameters in a Livestock Building †

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† Presented at the International Conference on Electronics, Engineering Physics and Earth Science (EEPES 2025), Alexandroupolis, Greece, 18–20 June 2025.

Abstract

This article presents a study related to the determination of the energy losses in the nodes of a wireless sensor network during its operation. The sensor network is designed to collect real-time data on some environmental parameters in a livestock building. Measurements of the charge level of the batteries powering the network nodes were carried out and models describing the process of battery discharge over time were obtained. It was found that the most suitable for describing the process of battery discharge over time is the linear model, with the coefficient of determination R^2 in this case varying between 0.96 and 0.99.

Keywords: wireless sensor network; energy efficiency; battery discharge modeling

Academic Editor: Grigor Mihaylov

Published: 27 August 2025

Citation: Georgieva, T.; Penchev, S.; Gaazi, B.; Nedelcheva, E.; Daskalov, P. Modeling Energy Losses in a Wireless Sensor Network for Monitoring Environmental Parameters in a Livestock Building. *Eng. Proc.* **2025**, *104*, 49. https://doi.org/10.3390/engproc2025104049

1. Introduction

Wireless sensor networks (WSNs) are commonly used to provide measurement and control activities in various areas of life. The spread of their use is related to their flexibility, low cost, and low complexity of implementation. In the agricultural domain, WSNs are a set of autonomous sensor nodes that can monitor and collect data about the environment in real time from different locations using various sensors. Then, this data is sent wirelessly to a central base station, where it is additionally processed and analyzed. The use of WSNs in precision agriculture offers a lot of advantages that have a major impact on the way farmers manage their business [1]. One of the main advantages of WSNs is that they provide farmers with a tool that helps them to control the farm conditions in real time. By using this sensor data, farmers are better prepared to react to changes in weather conditions or respond to threats like diseases or pests.

A well-known limitation of WSN deployments is the operating life of the sensor nodes. Mostly running on batteries as their energy source, the reduced battery capacity is the main limitation of the lifetime of the sensor node [2]. So, it is necessary to evaluate the battery capacity, lifetime, and behavior, keeping in mind the tasks performed by the network modules.

The estimation of battery life in WSN nodes is a complex task because of the multiple many factors affecting their performance [3], leading to nonlinear behavior over time [4–6]. Two major approaches to solving such tasks are known [7]: (i) hardware-based solutions, using control boards for monitoring the current state of the battery; and (ii) software-based solutions, in which the state of the battery is modeled mathematically.

Technical solutions related to the first approach can be found in so-called smart batteries, where integrated circuits provide data about voltage, temperature, current, and in some cases, about the operating behavior of the battery. They are usually included in laptops, smartphones, and cameras. However, the use of such solutions increases the batteries' production costs [8]. Usually, wireless sensor networks consist of a large number of nodes; therefore, in that case, the use of additional hardware to monitor the behavior of each node power source could be economically unprofitable.

Analytical battery models are usually based on a set of differential equations to estimate battery behavior. Such models are implemented in simulators in order to estimate the behavior of the WSN nodes before their actual deployment [9–11]. Real-world WSNs are usually based on low-cost hardware, so sometimes the possibility of using such analytical models along with such hardware is a question that needs to be evaluated. For that reason, some studies are published where the usefulness of analytical battery models with low complexity together with low-computational-power hardware is assessed [12–15].

This article presents a study related to the determination of the energy losses in the modules of a wireless sensor network during its operation. The sensor network is designed to collect real-time data on some environmental parameters in a livestock building. Measurements of the charge level of the batteries powering the nodes of the network were carried out and models describing the process of battery discharge over time were obtained.

2. Architecture and Basic Components of the Wireless Sensor Network

The architecture of the wireless sensor network is shown in Figure 1. The communication system includes a programmable logic controller, BECKOFF BC9000 (Beckhoff Automation GmbH & Co. KG, Verl, Germany), and wireless sensors that communicate (transmit/receive data) via an OPC server. The information received from the wireless sensors is transmitted through the base station to the personal computer, which, in turn, based on the received information, sends control signals to the controller in order to manage and control the microclimate parameters in the building.

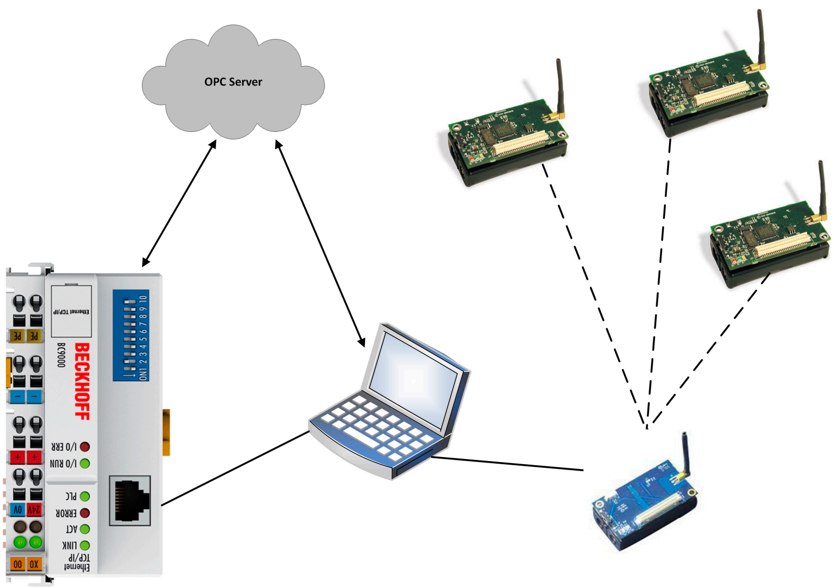

Figure 1. Architecture of the system for communication via OPC server between wireless sensors and PLC.

The MIB520 (Consulting Measurement Technology GmbH, Gilching, Germany) was chosen as the base station, and the MDA100 sensor modules were chosen. The MDA100 series sensors have a precision thermistor, a light sensor (photocell), and a common prototyping area.

The sensor modules must be programmed beforehand. This is carried out in the MoteView 1.2 programming environment. It configures the base station and sets a list of sensor modules from which it can read data.

Wireless Sensor Network Software

Software has been developed that enables communication between the controller and the computer via an OPC server (Figure 2), as well as communication with the sensors that report the necessary parameters for the system. For this purpose, the LabView programming environment has been used. The front panel of the graphical user interface is shown in Figure 3. The NI OPC server is used to configure the communication between the computer and the controller.

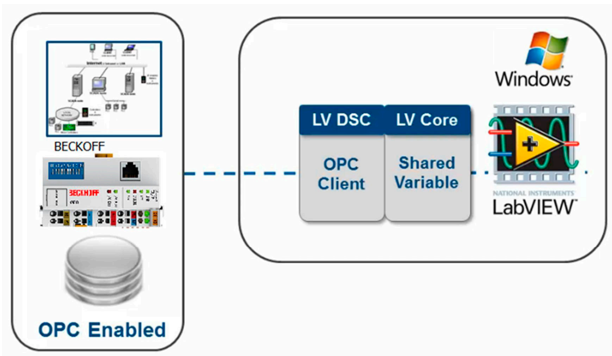

Figure 2. System communication with OPC server.

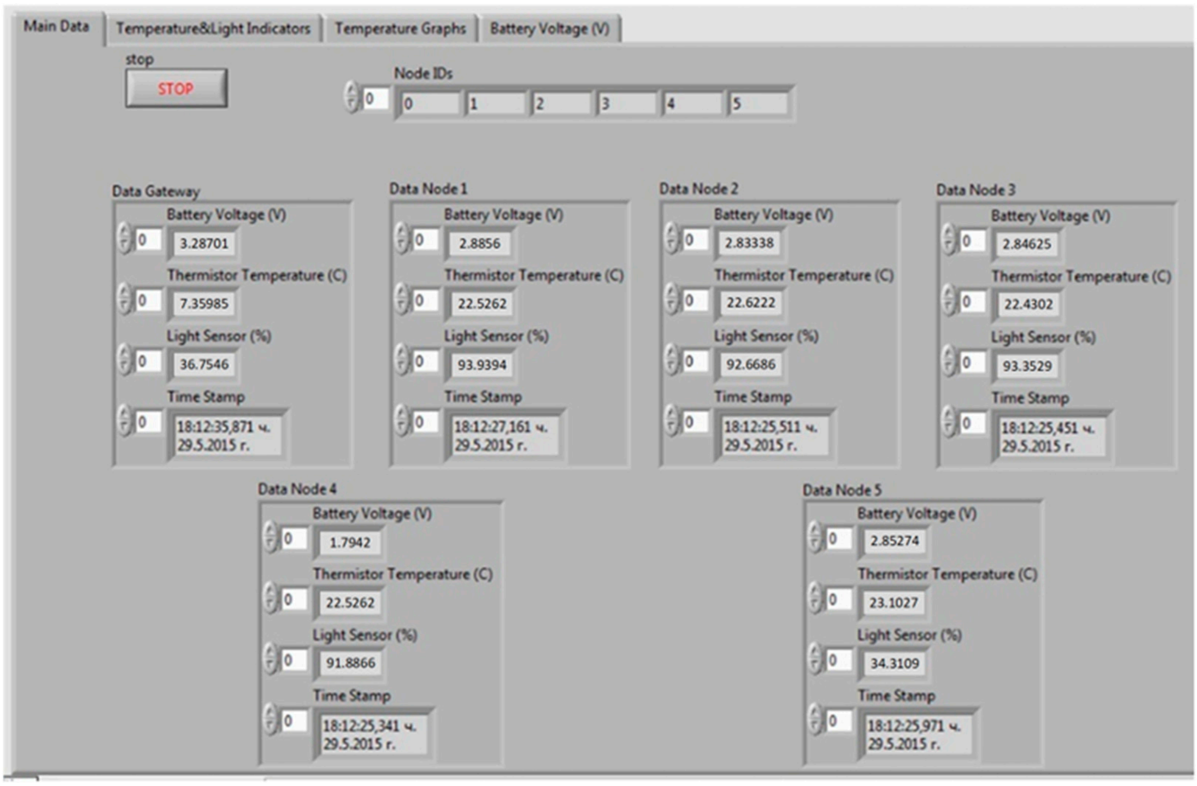

Figure 3. Front panel for sensor information visualization.

The graphical user interface visualizes data from temperature and light sensors in tabular and graphical form, as well as the current voltage of the batteries, powering the base station and individual nodes of the sensor network.

3. Modeling the Battery Discharge Process of Wireless Sensor Network Nodes

The system was studied in order to verify the duration of operation of individual nodes in the sensor network and to model the change in the voltage of the batteries supplying them. The models show the behavior of the supply voltage over time, during the normal operation of the sensors. They can be used to precisely monitor the condition of the batteries, in order to replace them in a timely manner for recharging or to warn of an upcoming replacement if their discharge rate begins to differ dramatically from that of the model.

Battery voltage measurements were taken on four sensor modules from the network every 10 min for 24 h of continuous operation. The selected modules were located in the parts of the livestock building furthest from the base station. During this period of time, the battery charge level decreased by more than half. Some variations in the data were observed, which were most likely due to measurement noise. Figure 4 presents some of these measurements (every hour).

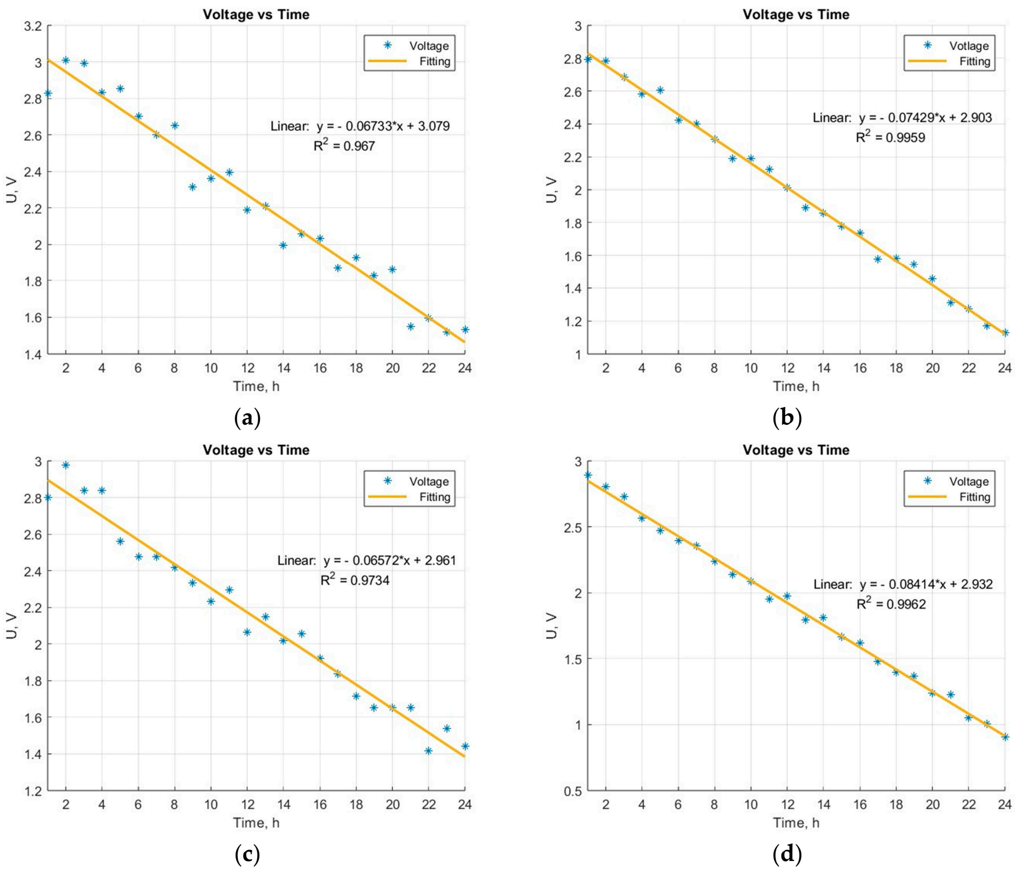

Figure 4. Battery voltage variation over time and the resulting linear regression models: (**a**) For node 1; (**b**) For node 2; (**c**) For node 3; and (**d**) For node 4.

Regression analysis was used to obtain the models. The best models, together with their coefficients of determination, are presented in Table 1.

Table 1. Results from regression analysis.

Node No.	Model Equation	R^2
Node 1	V = −0.0673x + 3.079	0.967
Node 2	V = −0.07429xT + 2.903	0.9959
Node 3	V = −0.06572xT + 2.961	0.9734
Node 4	V = −0.08414xT + 2.932	0.9962

The results show that the most suitable for describing the battery discharge process over time is the linear model, as Figure 4 and Table 1 show that the coefficient of determination R^2 in this case varies between 0.96 and 0.99. These models can be used to predict the time to reach the critical battery charge level set by the network operator, which will ensure a timely response without disrupting the normal operation of the system.

4. Conclusions

The architecture of a wireless sensor network for monitoring some environmental parameters in a livestock building is presented. The system consists of a personal computer, a programmable logic controller, and wireless sensors that communicate via an OPC server.

Software that ensures communication between the network modules via an OPC server and visualizes the measured parameters from the sensor nodes in digital and graphical form has been developed in the LabView environment.

Research has been conducted, and the variation in the voltage of the batteries powering the nodes in the sensor network has been modeled. The results show that the most suitable for describing the battery discharge process over time is the linear model, with the coefficient of determination R^2 in this case varying between 0.96 and 0.99.

The created models can be used to precisely monitor the condition of batteries, with the aim of timely replacement for recharging or to warn of impending replacement if their discharge rate begins to differ drastically from that of the model.

Author Contributions: Conceptualization, S.P. and P.D.; methodology, S.P.; software, B.G.; validation, P.D., T.G. and S.P.; formal analysis, E.N.; investigation, B.G.; resources, B.G.; data curation, S.P.; writing—original draft preparation, S.P.; writing—review and editing, T.G. and P.D.; visualization, E.N.; supervision, P.D.; project administration, T.G.; funding acquisition, T.G. All authors have read and agreed to the published version of the manuscript.

Funding: The research was conducted within the framework of the European Union—Next Generation EU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project № BG-RRP-2.013–0001-C01.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

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