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IFAC PapersOnLine 55-4 (2022) 254–259

A Concept for a Cloud-Driven Controller for Wireless Sensors in IoT Devices

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Abstract:
The paper presents an optimization algorithm applied to a cloud-driven controller for wireless sensors in Internet of Things (IoT) devices. The experiment investigates operational duty cycle control and energy management of a wireless sensor node device powered by prediction from global solar irradiance in the environment. Rapid increases in the development and growth of smart technologies is placing greater demands on optimizing computing power. The study attempted to manage and optimize wireless terminals using methods to adjust work cycles and planning. The study's contribution is a simulated wireless environmental IoT sensor node and cloud controller implemented in Matlab. The simulation examined energy management and optimization, supplemented by prediction from data measured at different locations in the period 2016–2019. The experiment investigated suitable modes of operation of the device according to data updates in the cloud. The controller was based on the following parameters: state of energy storage, number of failures relative to correctly performed device cycles, and predicted values for charging energy storage from the cloud.

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Keywords: WSN, IoT, optimization, energy management, cloud driven algorithm, cloud computing, wireless sensor node

1. INTRODUCTION

Major developments in Internet of Things (IoT) technologies requires continual progress in the development of algorithms. The need for energy harvesting is rising as demand increases for long-term applications in wireless sensor networks (WSNs) and IoT devices (Prauzek et al. (2022)). WSNs are commonly used to obtain tracking information or collect climatic, biological, population, environmental and surveillance data. Energy harvesting from the environment for the purpose of charging wireless sensor end devices is an expected requirement in the design of such systems. The main problem associated with the deployment of WSN equipment in remote areas and locations with poor accessibility is supplying power to these devices (Paterova et al. (2021)).

A typical scenario involves powering the terminal device of a wireless sensor for sustainable operation with energy obtained from the environment, primarily from solar energy (Yick et al. (2008)). Dynamic control is required to manage and optimize the energy consumption of the WSN device. We propose the use of methods which adjust the duty cycle of the device through interaction with the environment, and thereby set appropriate parameters which improve the WSN node's overall operation (Guy (2006)). The results were evaluated according to how well the adjustment of specific parameters satisfied the requirements of certain application areas.

The continuous development of smart networks has also spurred this ongoing process of advancement. Many researchers are still proposing newer and sophisticated solutions to implement such methods, for example, soft computing methods, evolutionary algorithms, and other machine learning methods (Prauzek and Konecny (2021)). Modular design allows extensible networks and the duplication or addition of similar components to accommodate network growth (Qin et al. (2016)).

Distinct types of neural network and evolution algorithms are among the most modern technologies applied in wireless sensor networks. These techniques are typically deployed in the cloud to process data collected from IoT devices and enable the design of procedures which take advantage of the cloud's enormous computing power and aid mobile devices in training computationally intensive models (Salman et al. (2019)). Another approach is the use of these models directly in the device (because of the significant financial overheads in data transmission and data privacy) (Matin and Islam (2012); Zhan et al. (2017)).

Finally, the selection of a suitable communications protocol which provides efficient data transfer is also crucial in designing a quality algorithm (e.g., LoRaWAN) (V. et al. (2022)).

The paper is organized as follows: Section 2 provides an overview of the key issues discussed by works related to WSN and optimization algorithms; Section 3 describes the experiment; Section 4 summarizes the results of the

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2022.06.042

experiment; Section 5 concludes the paper and outlines future applications of the work.

2. RELATED WORK

The publications mentioned below incorporate wireless node control principles in their studies. Wireless node control and suitable approaches are the key aspects in the wireless sensor network model design process. This section includes works which investigate the topic of wireless sensor node control. Some of the main technical aspects in the designs of these technologies are energy minimization, data compression schemes, network algorithms for optimization, and management of quality of service (Kaur and Mehta (2016)). Other important and often discussed topics are energy efficiency, quality of service and security management, all of which are indispensable considerations.

2.1 Energy management solutions

Singh et al. (2020) provide a broad survey and taxonomy of energy management schemes in wireless sensor networks. In this area, a key challenge is addressing issues that affect wireless sensor performance, especially in their individual characteristics, which include mainly energy constraints for proposed systems. One of the most effective solutions is management of the system's energy acquisition from alternative sources to limit the system's dependence on energy storage as much as possible. The study analyzed the energy consumption of various stages of wireless sensor networks and provided an overview of the following topics: battery management, end management equipment, balancing and energy management, energy management in data transmission.

Optimal solutions for wireless sensor node devices can extend network lifetime and manage power consumption. The studies below describe solutions which apply algorithms in the technical functions that monitor the status of wireless devices, the overall vitality of the sensor network, and the corresponding techniques and parameters of the system duty cycle (Kumar et al. (2019)). The aim of these solutions is to reduce the device's power consumption and thereby reduce the temperature value, which results in extended network lifetime. Experimental results demonstrated a 12–18 % extension of battery life by applying an optimal working cycle. A further improvement of 9 % was achieved in data compression in colder environments.

Sichitiu (2004) applied several power sources and corresponding methods to reduce power consumption in a wireless node. The most effective method of conserving energy and extending uptime was to switch off the wireless sensor device intermittently. This key factor and other aspects were examined in detail: inefficient listening during the transmission/reception of data, retransmission resulting from network collisions, control packet overload, unnecessarily high transmission power, and inefficient use of available energy resources. The main aim of the work was to produce a solution for the device working cycle, i.e., switching on/off according to the system's needs.

Liu et al. (2007) applied this strategy by using a system of matrices. First, the total consumption of the system was calculated, and then the sensor network was divided according to logically separate matrices so that mutually active sensors always covered the total monitored area. The aim of the experiment was to achieve the maximum possible network uptime.

2.2 Optimization solutions

Yan et al. (2003) investigated surface coverage by a single sensor. Failure of such a sensor results in the loss of information and data from the area it covers. The aim of the experiment was to set up a dataset system which functioned and slept gradually. Application of this principle achieved full coverage and complete monitoring of an area with functional sensors. Th system was optimized and achieved maximum operating time.

Optimizing and extending the operating time of an energy device (e.g., battery or other source) is one of the main aspects of extending the lifetime of a wireless sensor network. The condition or endurance of the battery is an important characteristic during discharge in achieving the optimal duty cycle time of a wireless sensor device; it is a very important parameter in designing a solution. Chanagala and Khan (2017) considered this parameter in a solution for extending the operation of a wireless sensor node's power supply (lithium-ion battery).

Controlling the work cycle with a genetic algorithm is one possibility for optimizing and improving the lifetime of a wireless sensor network. Bhulania et al. (2016) attempted to improve the work cycles of a wireless sensor networks using a genetic algorithm and network coding. The authors applied a genetic algorithm (GA) to optimize a multi-hop sensor network in two phases. The study compared the performance of the system using the GA, examining average latency in detail, to a system which did not use this method. The proposed method applied a genetic domain to the network service life cycle of the sensor node device.

Hsu et al. (2015) explored the wireless connection of a sensor node device. The device was powered by solar energy to provide sustainable operation and improve its viability. The authors created a fuzzy inference system with feedback learning method applied to dynamically control the wireless node's energy supply from the environment. By interacting with the given environment, the proposed method modified the work cycle and the system's sensor/transmission tasks.

3. EXPERIMENT

The experiment addressed the monitoring, work cycle and prediction principles which govern a wireless sensor device. The experiment focused on selection of the device's correct operating mode according to the data transfer frequency and the energy storage status. According to these parameters, additional functions within the wireless node can then be planned.

3.1 Data

The experiment used ten-minute data from the period 2016–2019. The data recorded the following parameters: wind speed (F) in metres per second, air pressure (P) in hectopascals, global radiation (RGLB10) in watts per

Measured parameter	Abbreviation	Unit
Time	t	s
Air temperature	T	^oC
Air pressure	P	hPa
Global radiation	RGLB10	W/m^2
Wind speed	F	m/s
Total precipitation	SRA10M	mm
Soil temperature	T	^oC

Table 1. List of measured parameters and units in the data provided by Czech Hydrometeorological Institute.

square metre, total precipitation (SRA10M) in millimetres, air temperature (T) in Celsius, soil temperature at depths of 5 cm, 10 cm, 20 cm, 50 cm, and 100 cm in Celcius. The data was obtained from Churáňov meteorological station (C1CHUR01), Mosnov meteorological station (O1MOSN01) and 16 other locations.

The following section describes a simulated node device which allowed various configurations and parameters to be tested before implementation of the control system in real hardware. Real measured meteorological data acquired in the period 2016–2019 from different meteorological stations in the Czech republic was used to test the capabilities of the algorithm. The results showed that setting individual modes was crucial to sensor node performance. When set improperly, the system had a tendency to fall short of its potential lifetime by decreasing its energy storage.

3.2 Description of the Experiment

The study developed suitable methods to monitor, optimize and control the model of a wireless sensor IoT device. The model consisted of a network with a wireless sensor node. Future models will contain several homogeneous nodes distributed across selected areas of the Czech Republic and be processed in the cloud and update parameters at regular intervals according to the needs of the system. Appropriate design will also optimize monitoring in the given environment. The method could therefore also be used for data collection.

The aim behind developing this method was to increase the operational capability of a wireless sensor node and its wireless connection and to increase the required lifetime of the entire network while maintaining quality.

One of the main points in optimizing the device was to prolong its lifetime and the operational reliability of the equipment. The device's work cycle can be controlled in several ways, one of which is to use a central component such as the cloud so that all parts of the network are able to communicate.

LoRa is a collection of technologies used in the physical layers of LoRaWAN networks. LoRa is characterized by low energy consumption during transmission; the endurance of end devices is approximately 10 years, and the bit rate is set, for example, to a low 27 kb/s and uses a Spreading Factor (SF) of 7 (Novotny (2018)). The following settings were applied in this scenario: transmission power TX = 3, data rate value DR = 2, Payload = 8 B.

The LoRaWAN network architecture is deployed in a star-of-stars topology, in which the gateway transmits messages between the end devices and the central network server (i.e., the cloud). All modes are bidirectional, and there is support for multicast groups to efficiently use the spectrum during tasks such as firmware updates or other bulk distribution reports (Sigut (2017); Sornin et al. (2015)).

For the needs of the model, a duty cycle management method was applied to optimize and extend operation of the wireless terminal and thereby improve the operational lifetime and viability of the unit and lower power consumption (Fan et al. (2005)). The method applied data on the embedded micro-operative system's use of energy to reduce the node's energy consumption. This procedure regulated the power management in the device to set the appropriate mode: sleep state, active, etc.

The wireless sensor node was powered with a rechargeable battery and equipped with an energy harvesting unit. Communication between these parts was achieved through the control management unit. Global irradiance measured from the sun was used to predict the expected value for delivery to the system; energy was supplied to the terminal through the energy management unit. The management unit charged the battery if a sufficient quantity of energy was collected and delivered to the unit during energy harvest. A solar model calculator was used to determine the correct amount of energy obtained from global irradiance.

3.3 Experiment Parameters

Table 2 lists the node's parameters and values measured during operation. These data were obtained from standard measurements in an experimental setup and used as input for the simulator.

This sub-section describes the management configuration of the simulated wireless device and update procedure based on historically measured data. The design of a method suitable for controlling a wireless sensor node using work cycle management was supplemented with optimization of the proposed model. System operation, which is based on environmental data and subsequent data transmission to a network, is governed by an algorithm which does not have any prior knowledge of its environment. The experiment in the study consisted of four modes. Ten-minute temperature values in degrees Celsius and global irradiation values are sent to the simulation as input data. Therefore, the simulation step is performed every 10 minutes. The data is then forwarded with a given time interval. The time interval is determined by the actual mode or state in which the device operates.

The device's mode depends on the state of energy storage and predicted energy. These parameters are computed in the cloud based on the historical data from individual stations.

In the next phase, the experiment will contain additional stations. The aim of the experiment is to achieve a modular system so that the same or a similar algorithm can be applied to other WSN IoT devices.

3.4 Fuzzy control settings

Modes are set according to individual states using simple IF-THEN fuzzy rules. The rule settings are shown below.

Parameter	Value
Solar panel area	648 mm^2
Solar panel efficiency	21 %
System Voltage	3.3 V ± 0.1 V
Sleep current	190 µA
Standby consumption	3.3 mJ
Sensing consumption	2 J
Data Storage consumption	8 mJ
Data Transmission consumption	30 mJ
Energy buffer capacity	750 J

Table 2. Paramters of the real hardware model.

State (-)	Time (minute)	State of ES (%)
1	60	(50, 60, 100)
2	120	(35, 50, 65)
3	240	(10, 25, 40)
4	1440	(0, 0, 20)

Table 3. Operating modes set according to the fuzzy rules.

Average Eh per(hours)	Time (minute)	State of ES (%)
2	10 – 60	> 60
8	240	>35
24	1440	>15

Table 4. Parameter settings for selecting a suitable operating mode.

The mode selection settings work according to the energy storage status. The specific percentage values are listed in Table 3.

After the error is counted, the predicted value is averaged over the selected time interval according to the terminal's appropriately selected state. The intervals at which the predicted values are calculated ensure that data is not transmitted too frequently when energy storage is low and that the node also has as much data as possible for prediction to properly control the system. Table 4 shows the settings for calculating the predicted value for charging the terminal device according to its current state.

3.5 Simulation settings

The simulation set the device's operating mode. Each time the simulation was run, the old settings were checked and compared to the new ones. When the simulation concluded that the new settings were more advantageous, the controller changed the state. The state was changed according to two parameters:

- the current state of energy storage, supplemented by a predicted value calculated in the cloud;
- the number of failures relative to the correctly performed device cycles in the given simulation step.

This is the basic principle of the process in Algorithm 1.

3.6 Calculation of predicted values

The predicted value of the amount of energy that the device obtains was calculated according to hydrometeorological data for global irradiance from the Meteorological Institute. The global irradiance value was transmitted to the cloud every 10 minutes. In the cloud, for each step

Algorithm 1 Optimization algorithm for a WSN node

```
procedure OPTIMIZATION(a, b)
    System Initialization
    Receive the initialization model parameters
    Get the predicted value (PV)
    new SoES= PV + old SoES
    if State of ES = > 60 then    ▷ Fuzzy rules model for choose state
        State = 1
        if State of ES > 35 1 then
            State = 2
        else if State of ES > 15  then
            State = 3
        else
            State = 4
        end if
    end if
end procedure
```

of the simulation, one value was taken from the data set, and the energy gain was calculated according to the solar calculator. The temperature value was then processed according to calculation model for the solar panel (for more detailed information, see the previous publication). In calculating the predicted rate, the DC/DC converter was also taken into account in the simulation. We have to take into account that the error was also measured with a certain degree of uncertainty. The input predicted value was therefore multiplied by an error with even distribution. The value was adjusted according to the following equation:

$$\mathrm{Err} = 0.9 \cdot x + 0.1 \cdot x + sz \quad (1)$$

For prediction, the ten-minute values were summed, and the value of the energy collected from the two-hour time interval was transmitted to the device. This was applied when a data packet was not sent or received every 10 minutes but with a different time interval according to the device's current state. Table 3 provides more detail. This value was then added to the current state of energy storage.

4. RESULTS

The study presents an algorithm which plans and adjusts the work cycles of an EWSN node and is able to control the energy management of a solar-powered system. The study introduces novel algorithm control based on a fuzzy inference system (FIS) and four modes for different settings according to the actual state of energy storage. This approach provides a suitable solution for an energy harvesting EWSN and can be extended for deployment in many locations. The results of the experimental based on the hardware model improved the number of operational cycles and provided a better fail/correct ratio then previous studies. In addition, overcharging and failure stability improved, and the application was able to work without significant loss of energy and reliability.

Functional ratio calculation The functional ratio R is calculated as the number of states when the device failed

S_F versus the number of states when the device operate correctly:

$$R = \frac{S_F}{S_R} \tag{2}$$

The chart below illustrates the results for energy storage.

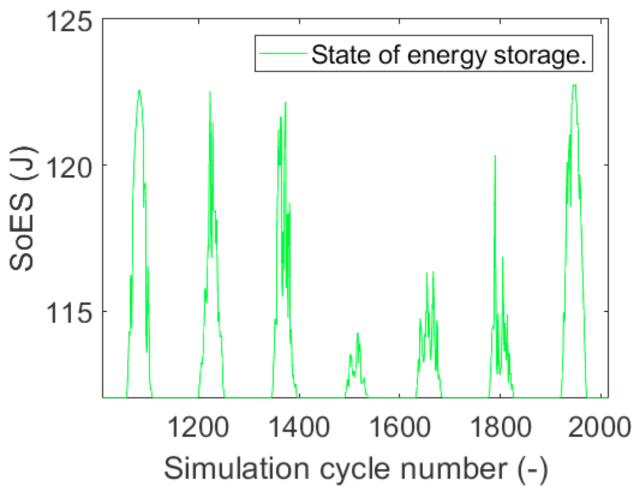

Fig. 1. State of energy storage in the simulation for one week.

The chart below illustrates the results for predicted values:

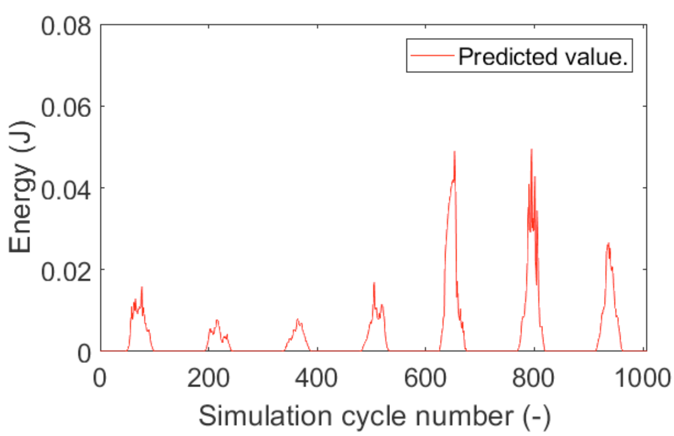

Fig. 2. Predicted values in the simulation for one week.

Figure 1 charts the WSN node charging according to predicted values. Prediction eliminated the complete failure of the device from 6.58.

These interactions were evaluated according to fuzzy inference rules, which express duty cycle adjustments to current energy and requirements for neutrality. The experimental results revealed that the proposed method has better convergence and fewer energy deviations than other methods.

The chart below illustrates the results for predicted values. The graph 3 shows how the value of the predicted value changes according to the season and other phases of the day.

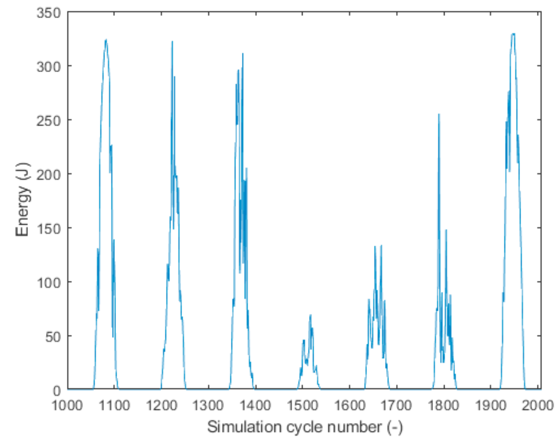

Fig. 3. Predicted values in the simulation for different week.

5. CONCLUSION AND FUTURE WORK

The paper describes a simulation framework applied to a wireless sensor IoT device for energy harvesting prediction in the cloud. The simulation was designed to optimize energy management by predicting the amount of energy in the system and and the system's reliability. The resulting code is highly modular and flexible, and additional wireless sensor nodes will be added in the next phase of the research. Consequently, we will use historically measured data from other stations to improve prediction. The system used historical data to emulate node functionality in the intended target environment. This approach allowed evaluation of the node and its control optimization algorithms and a comparison with other methods.

Future work has much research potential. One opportunity is in conducting extensive simulations for other stations and their collected data (testing in various locations) and discovering how the system behaves in both stable and unstable weather conditions. Future testing would therefore be performed with data from various locations in the Czech Republic which demonstrate differing climatic conditions. Another research challenge lies in modifying the presented algorithm to use machine learning and soft computing methods and thus reduce computational complexity, provide better analysis of the monitored environment, and improve the wireless sensor network's operating lifetime.

ACKNOWLEDGEMENTS

This work was supported by the project SP2022/11, "Development of algorithms and systems for control, measurement and safety applications VIII" of the Student Grant System, VSB-TU Ostrava. This work was also supported by the European Regional Development Fund in the Research Centre of Advanced Mechatronic Systems project, project number CZ.02.1.01/0.0/0.0/16_019/0000867 under the Operational Programme Research, Development and Education. This work received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 856670.

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