HOLISTIC INTEGRATION OF ZIGBEE TECHNOLOGY FOR OPTIMIZED SENSOR CALIBRATION IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Ensuring proper sensor functionality requires periodic calibration in an accredited laboratory, which traditionally involves temporarily removing the sensor from operation. To improve this process and avoid disrupting sensor activity, we propose using mesh networks with ZigBee technology. In this setup, sensors are represented as nodes within the network, enabling continuous wireless communication with a central node (gateway) responsible for data storage and processing. The central node monitors state changes and communicates with all network nodes, assessing deviations from reference sensor values based on data collected from other nodes. This real-time monitoring allows for dynamic adjustment of calibration parameters without interrupting sensor operation. Nodes are categorized into reference and regular types, with their definitions stored in a dynamic state table. This classification facilitates efficient communication and parameter retrieval. Advanced algorithms can then adjust calibration settings based on real-time data, improving the accuracy and reliability of the wireless sensor network (WSN). This method ensures continuous precision and robustness in sensor performance, adapting calibration dynamically to maintain network reliability.

KEYWORDS

Dynamic State Management, Sensor Calibration, ZigBee Technology, Wireless Sensor Networks (WSN), Real-Time Data Processing.

1. INTRODUCTION

In current practice, wireless sensor networks are used in a variety of applications, including environmental monitoring (e.g. temperature, humidity, air quality), resource monitoring in industrial processes, infrastructure monitoring (e.g. road, bridge condition monitoring), smart agriculture, security and many others. To enhance and accelerate the deployment of communication systems between nodes, ZigBee technology is utilized, which has increasingly gained prominence as a commercial solution. Communication based on this technology allows the network to be flexible and easy to expand.

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In this paper, we focus on the proposed solution for facilitating and speeding up calibration based on the mentioned technologies. The advantage of this approach is significant for large systems that have a large number of sensors.

In order to carry out all the calibration processes, the main step is to physically switch off the required sensor and transfer it to the laboratory in order to carry out the calibration under special conditions. The use of a network would facilitate the current calibration method and the sensor itself would not have to be switched off. This method streamlines the calibration process and reduces costs.

Through various researches, the concept of blind calibration has been presented which is designed for general sensor networks. The idea is to achieve great similarity in the measurements of all sensors in the network for the same purpose through this concept [1]. This method of testing does not always give correct results, but through a larger number of measurements and the inclusion of comparison with a reference sensor, this concept could be applied through a wireless network of sensors. The mesh network through various applications has shown flexibility and cost reduction [2][3]. This network topology allows all network participants to send and receive data, thus all sensors within the sensor network can communicate with each other.

The rest of the work is organized through four sections. Section 2 introduces wireless sensor network technologies and ZigBee technologies. Section 3 shows the proposal of the system architecture and Section 4 describes the implementation of the calibration based on the proposed architecture. In Section V conclusion of the work.

2. WSN AND ZIGBEE

A wireless sensor network (WSN) is a self-organizing, ad hoc multi-hop network consisting of sensors distributed over an extensive area [4]. It operates as a distributed real-time system where nodes are capable of both transmitting and receiving data. This enables the WSN to simultaneously collect physical parameters, process data in real time, and facilitate wireless communication, thereby allowing for efficient and synchronized data management throughout the network.

The WSN comprises numerous sensor nodes that generate readings, which are then transmitted through multi-hop paths to a designated node for data aggregation, known as the sink [5].

There are two main types of nodes within this system: sensor nodes and coordinator nodes. Sensor nodes are responsible for detecting environmental changes, such as variations in temperature and humidity, and transmitting the collected data to the network. Coordinator nodes, on the other hand, are tasked with gathering the data sent by sensor nodes and relaying it either to end users or to processing systems for further analysis [6].

ZigBee is a worldwide open standard of low-speed wireless networking based on IEEE 802.15.4.

The aim of this standard is to enable [7]:

- Low cost
- Ultra-low power consumption
- Use of unlicensed radio bands
- Cheap and easy installation
- Flexible and extendable networks

- Integrated solutions for message routing

The mentioned characteristics enable quick installation of external power supplies without the need for cables due to low levels of vibration during operation.

This technology finds its application in smart home communication, security systems and remote control and reading of devices. Compared to other wireless protocols such as Bluetooth (802.11), ZigBee exhibits a wide range in communication distance and a low transmission rate. It is characterized by fast and short transmission of text format. The figure (Figure 1) below shows wireless network protocols with an emphasis on two characteristics, wireless radio range and data transfer rate [8].

Routing a message through the network from one node to another depends on the network topology, which is divided into star, tree and mesh.

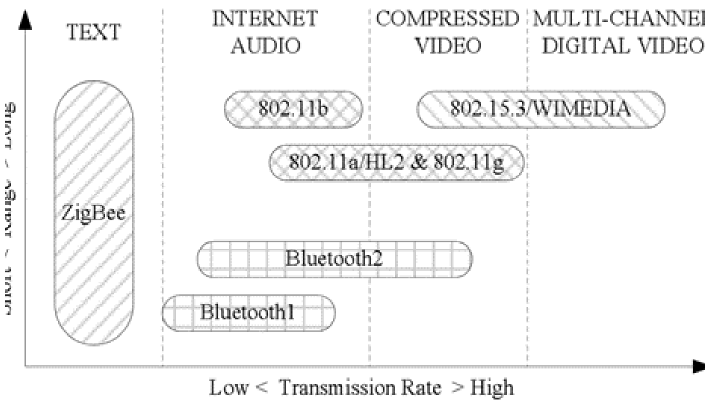

Figure 1. Wireless landscape

Star topology relies on a central node and all messages travel through it.
A tree topology has a main node at the top that branches into branches and leaves. In order for the message to reach the required destination, it travels up the tree and then down the chain.
The mesh topology is the most similar to the tree topology, only that the nodes have a direct connection to other nodes.

Unlike star topology, where a single coordinator node manages and distributes network traffic, a mesh network allows for communication without relying on a central coordinator. In a mesh network, nodes act as routers, creating a flexible and reliable structure that supports the mobility of end nodes. This feature enables ZigBee technology to cover extensive areas, making it applicable across various industries.

ZigBee technology has been effectively implemented in diverse fields, including smart homes and cities, agriculture, industrial production, and more. The choice of ZigBee for communication within wireless sensor networks (WSN) is driven by its low-cost, low-power, and multifunctional sensor nodes.

The mesh network architecture enables long-distance communication. One notable application of this technology is in the wireless testing of sensor performance and accuracy. Traditionally, sensor testing required disconnecting sensors from operation and conducting tests under laboratory conditions. Utilizing wireless methods for sensor verification can reduce costs and enhance system effectiveness. For this approach to be effective, it is crucial to define node types within the network, which ZigBee communication supports. One effective method is to establish a dynamic node state table to define and manage all nodes within the system.

3. NETWORK SYSTEM ARCHITECTURE

In order to take full advantage of the advantages of ZigBee technology, the definition of node types is performed depending on the role in the system, structuring and storage of data exchanged between nodes.

3.1. Types of Nodes

By using a mesh network, it is necessary to introduce the definition of network nodes in order to adapt to the solution of the calibration problem within the wireless sensor network.

Nodes are divided based on their roles in the network into the main node (orange), reference (blue) and regular (green) nodes (Figure 2).

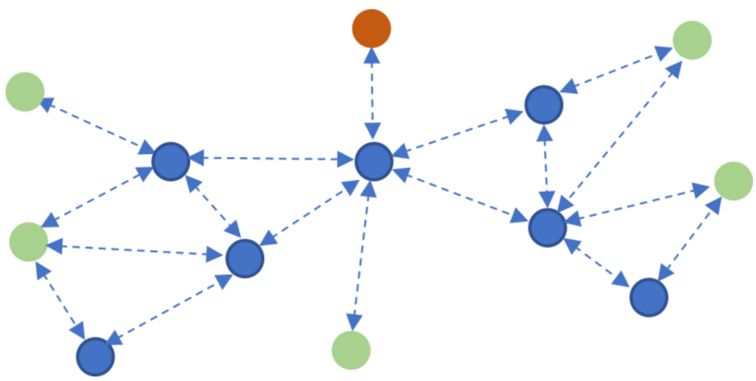

Figure 2. Communication between different types of nodes

The main or input node has the role of coordination in the system as well as receiving and sending data outside the network. Within the main node, information related to the state of nodes in the network and data measured through measurements on reference and regular nodes are stored.

Reference nodes are occasionally active nodes within the network that assume their role at certain time intervals. After successful measurements, they are disconnected from the network.

Regular nodes are all other nodes that have a daily function within the sensor wireless network. Through this system functioning model, their work is constant without planned disconnections from the network, as long as they provide the required functionality.

3.2. Table of Dynamic States

In order for communication to be uninterrupted and reliable in the network, the state of each node and the type of node it belongs to are recorded. On the basis of the above information, a decision is made about the necessary storage of parameters and the analysis thereof. The parameters are entered into the table of dynamic states, which has the following structure:

- Node address
- Node type
- Purpose/Function
- Routing time
- Status

Based on the routing time, an assessment is made on the need for a new node status update. The state of a node determines its activity in the network, which can be active or deactivated.

Nodes that cannot be accessed during each subsequent routing are given the status deactivated, while deactivated nodes are examined first with each pass. By definition, if a node is inactive in the network for a certain period, it is deleted from the status table.

Recognizing a new node in the network during routing, its function or type of sensor in the WSN system is recorded, the node type is basically added for regular, while in reference connection situations this type changes and the status of the node becomes active and visible in every subsequent routing.

The table is stored on the main node to facilitate subsequent data analysis because all data is available in one place.

3.3. Table of Sensor Parameters

During dynamic state table routing through the network, nodes forward their sensor reading parameters to the master node. All measurement parameters for all sensors in the network are stored within the main node. For these needs, a table is created that records the address of the node, the type of measurement, the time of measurement and the values of the performed measurements. Based on the entered data, it is possible to follow the complete measurement history for each node in the network from the beginning of its activation. Based on the stated values of the sensors, it is possible to establish deviations in the operation of each sensor in different conditions, and based on the data from the table of dynamic states, the type of node is determined. In order for the calibration to be carried out successfully after storage, on the basis of establishing the type of node, the reference values for the selected sensors are determined, on the basis of which the calibration process is entered.

4. SENSOR CALIBRATION IN WSN SYSTEM

Wireless sensor networks usually consist of inferior sensors that are deeply integrated into the physical environment and as a result, the performance of the network is undermined by poor hardware and sums in data measurement [9]. Through various researches, calibration solutions have been proposed at the device level, which do not perform well in larger systems.

Through this work, a new concept of thinking within the mesh network is explained, with the definition of communication between nodes and the definition of data types in the system. Stored data within the main node contributes to tracking deviations of regular sensors in operation. With this work model, calibration includes a reference model that is defined in the system as a reference node, based on the parameters of which comparison is made with regular nodes of the same type of purpose.

During the sensor calibration, the measurement data is stored on the main node in the network, while the regular nodes, as permanent participants in the communication, only perform their measurement function.

Reference nodes are part of the system while measuring in similar conditions based on other sensors under test. During calibration, it is possible to take one or more sensors into the process, given that the architecture explained in Section 3 allows communication with multiple sensors and that all data is related to measurements on the main node, which has recorded the complete history of a particular sensor.

In addition to this, the calibration process incorporates advanced algorithms that adjust for environmental variations and sensor drift over time. By continuously comparing the measurements of the regular sensors to those of the reference node, the system can dynamically update calibration parameters and ensure that sensor data remains accurate and reliable. This approach not only improves the overall accuracy of the sensor network but also enhances the robustness of the network by minimizing the impact of individual sensor failures or discrepancies. Thus, this calibration method represents a significant advancement in maintaining the integrity and performance of wireless sensor networks.

5. CONCLUSION

The comparison between the wireless calibration model and traditional methods highlights the growing demand for larger scales and more nodes in wireless sensor network systems. ZigBee technology plays a pivotal role in supporting this model, enabling effective management through the definition of dynamic states, assignment of node types, and data storage. This capability provides comprehensive control over the network and fosters an environment conducive to expanding functionality and exploring new applications.

This study marks the initial phase in investigating sophisticated calibration techniques for wireless sensor networks. Future research will involve extensive testing to assess the calibration model's performance under various conditions. The objective of these tests [10] is to determine the most effective components of the system, identify optimal aspects of the calibration model, and recognize areas for potential improvement. The findings from this testing phase will be essential for refining the calibration process, improving the accuracy and reliability of the sensor network, and directing future advancements in this domain.

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