THERMAL SENSOR BASED OCCUPANCY DETECTION FOR ENERGY OPTIMIZATION (DETECTHER) ELEKON

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Abstract. This project addresses the growing need for efficient energy management in the hospitality sector by accurately detecting room occupancy and activating energy systems only when necessary. Unlike conventional motion sensors, which often fail to detect stationary individuals, our system employs a thermal sensor (D6T-32L-01A) to improve occupancy detection while preserving privacy. A Raspberry Pi-based Room Control Unit (RCU) processes this data to automate lighting control. To enhance accuracy, machine learning models, including CNN, LSTM, and YOLO are utilized. A centralized interface allows technical staff to monitor and adjust energy settings in real-time. The performance of the system will be evaluated through simulations and field tests in the model plot rooms. The expected result is a scalable and privacy-conscious energy management system capable of reducing energy consumption by approximately 20% while offering enhanced operational oversight and sustainability for facility managers.

PROJECT DESCRIPTION

The smart room and building concept comes from the need for energy efficiency. These systems enable automatic control of energy-consuming devices such as lighting and ventilation. A smart room is a room equipped with microprocessors and sensors, connected to a central computer for monitoring [1]. Smart rooms and smart buildings help achieve several goals [1]: reducing unnecessary energy use, improving the overall system operation, increasing environmental awareness, and ensuring more reliable system performance.

Elekon is a company that focuses on automation, lighting, security, and building management [2]. The smart room and building management concept fits perfectly with Elekon's principles. The company is already developing a smart room system for hotels, airports, and other facilities, called the Guest Room Management System.

Our project aims to deliver a more advanced version of existing room automation systems by replacing standard detection methods with thermal sensing technology for more accurate human presence detection. This approach offers a privacy-preserving solution. It avoids capturing personally identifiable information. Moreover, no such product currently exists in Türkiye, making our system both locally developed and innovative [3]. The primary objective is to reduce energy consumption by automatically controlling lighting based on real-time occupancy. To achieve this, we apply machine learning algorithms to thermal sensor data, enabling reliable and intelligent occupancy detection.

Several products similar to the one being developed already exist. Tektelic, a Canadian company, produces the VIVID sensor, which uses a PIR sensor for detection, addressing privacy concerns but raising issues with accuracy [4]. Schneider, a French firm, manufactures the SpaceLogic Insight Sensor, which utilizes IR sensors to ensure both high accuracy and privacy, anonymously and accurately counting people in a room [5]. Interact offers a smart control unit that relies on motion sensors for occupancy detection, a standard but less advanced method [6]. Calumino, specializing in intelligent thermal sensing, provides the world's first thermal sensor combined with on-edge processing, preserving complete privacy by avoiding the capture of personally identifiable information (PII) [7]. Although these companies share similar goals, they differ in important ways. Calumino stands out for its strong privacy-preserving design. However, thermal sensor-based systems like those from Calumino, Tektelic, Schneider, and Elekon generally achieve more accurate occupancy detection than motion sensor-based systems like Interact's. Economically, while foreign products such as those from Tektelic, Calumino, or Schneider are viable options, Elekon's locally produced system offers major advantages: it supports the national economy, provides easier access to services, and delivers a more affordable solution within the local market.

The product includes a box with a Raspberry Pi, thermal sensor, power supply, and external components such as an Ethernet module. It connects to a Room Control Unit (RCU) and a user interface. The system is designed to work independently and not as part of a larger building automation system. The development process consists of four main stages. The first stage is hardware and embedded system design, which covers PCB layout, power supply integration, WIZnet module implementation, and sensor connection. The second stage is software and backend development, where the sensor is operated, data is collected and stored, and integration with the company-provided RCU is achieved. The third stage involves machine learning, where we train a human detection model using YOLO on camera images and align the outputs with thermal sensor readings, enabling detection from thermal data alone. Finally, in the frontend development stage, a user-friendly interface is designed to allow users to view thermal images, see detection results and statistics, and interact with both the Raspberry Pi and the RCU. The overall project is depicted in the Big Picture shown below in Figure 1.

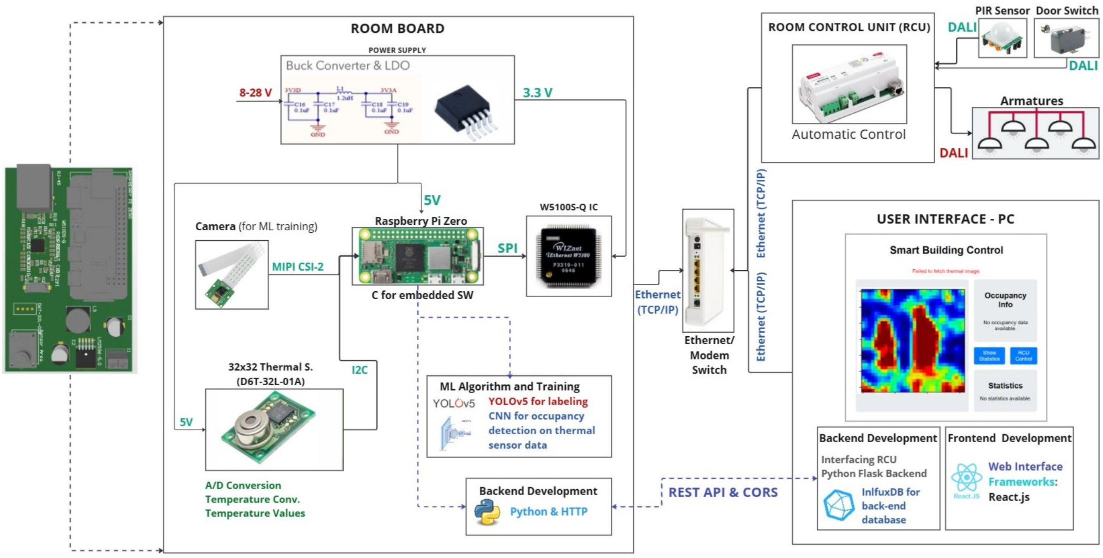

FIGURE 1. Big picture of the project

MILESTONES

- **First Milestone: Research**
  The first milestone, Research and Analysis, forms the foundation of the project. In this phase, the team reviewed existing technologies, analyzed project requirements, and researched the market for suitable occupancy detection and energy-saving solutions. This process helped the team clearly understand the project's goals, technical needs, and constraints, leading to the selection of key components like the Raspberry Pi Zero 2 W and the Omron D6T-32L-01A thermal sensor. The milestone is considered complete once the project context is fully understood and the appropriate components are chosen within the budget.
- **Second Milestone: Hardware Design**
  The next important step is Hardware Design, where the goal is to create a reliable setup for gathering data. This involves designing a steady power

supply to keep all parts of the system running smoothly and implementing the WIZnet ethernet module, thermal sensor and Raspberry Pi on a single PCB . Ensuring a stable power supply is essential because power fluctuations could lead to unreliable data. The thermal sensor's setup is tested to make sure it captures data accurately under various conditions.

- **Third Milestone: Software Design**
  Software design is the third main milestone, focusing on creating smooth communication between the hardware parts and setting up real-time data processing for occupancy detection. During this phase, the team establishes ways for data to transfer smoothly between devices and programs the Raspberry Pi to handle real-time data from the sensor. This includes configuring Ethernet and I^2C connections to ensure they work reliably.
- **Fourth Milestone: ML and Algorithm Design**
  In the Machine Learning Algorithm Implementation phase, the team works on improving the accuracy of occupancy detection by analyzing thermal data with a machine learning model. This model learns from the data collected by the thermal sensor and adjusts its detection approach based on different room conditions. The milestone is achieved when the model accurately detects occupancy and adapts to varying room conditions. This is an important part of the project's energy-saving goal, allowing the system to make smarter decisions about energy use based on actual room occupancy.
- **Fifth Milestone: Backend Design**
  The backend milestone involves integrating the company-provided RCU with the system we are developing. The goal is to enable the RCU to adjust the lighting accordingly based on the presence-absence data received from the Raspberry Pi, which processes input from both the thermal sensor and the PIR sensor. Additionally, at this stage, we aim to ensure that the data in the system is shared with the user interface. In this way, the Raspberry Pi backend and the user interface backend will be in communication with each other.
- **Sixth Milestone: Frontend Design**
  The Frontend Interface and User Testing milestone focuses on creating an easy-to-use interface where staff can monitor and control room occupancy data. Built with React.js, the interface shows real-time visuals of occupancy data and provides options to manage energy settings. This interface is essential because it allows staff to interact with the system's data and make informed energy management decisions.
- **Seventh Milestone: Final Testing and System Integration**
  The final milestone, Final Testing and System Integration, ensures that all parts of detecTHER work together as a complete system under real-world conditions. This phase involves testing the entire setup to confirm that occupancy detection is accurate, data transmission is reliable, and all components operate together smoothly.

DESIGN DESCRIPTION

The system was developed through a structured approach combining hardware, embedded software, machine learning, and user interface components into an energy-efficient room management platform. Design phases included simulation, prototyping, and empirical validation. The thermal sensing subsystem employed the Omron D6T-32L-01A sensor for its high-resolution 32×32 matrix and I2C interface. Initial tests confirmed its ability to detect stationary human presence, outperforming conventional motion sensors. A Raspberry Pi Zero 2 W served as the processing unit, with the sensor connected via I2C. Communication stability was enhanced by clock tuning, Gaussian filtering, and retry mechanisms. A custom Ethernet module built around the WIZnet W5100S chip provided stable TCP/IP communication over SPI. Static MAC addressing and device tree overlay adjustments ensured consistent network identification. Power delivery was handled by LM2596-5.0 and LM2575S-3.3 buck converters, supplying regulated 5V and 3.3V outputs to the system. The PCB, designed using Altium Designer, featured elevated sensor mounts and JST headers to accommodate physical integration constraints.

The machine learning pipeline involved synchronized thermal and camera recordings. A pre-trained YOLO model labeled camera footage, and corresponding annotations were transferred to thermal frames. CNNs were trained for binary and multi-class occupancy detection, then converted to TensorFlow Lite for on-device inference. Backend services were implemented with Python Flask, MQTT, and InfluxDB for control and data visualization. TCP communication enabled real-time interaction with the Room Control Unit (RCU) for lighting and HVAC automation. The frontend, built with React.js and Grafana, provided dashboards for thermal mapping, system status, and manual overrides. Integration with Elekon's RCU included PIR and door switch data to reduce false positives and improve reliability. The system is scalable, privacy-conscious, and compliant with safety and energy standards, making it suitable for hotel, residential, and commercial applications.

RESULTS AND PERFORMANCE EVALUATION

The project system underwent extensive laboratory testing, validation in controlled environments, and simulated deployment scenarios to evaluate its effectiveness in occupancy-based energy optimization. The assessment procedure emphasized functional accuracy, system responsiveness, power efficiency, and integration fidelity, all measured against established functional and non-functional criteria.

The system's ability to detect and classify room occupancy using low-resolution thermal data was a key evaluation criterion. To achieve this, a convolutional neural network (CNN) was trained on over 40,000 labeled image pairs generated from synchronized thermal sensor and camera recordings. The model achieved 92.1% accuracy in binary classification tasks, distinguishing between occupied and unoccupied states, and 77.9% accuracy in multi-class classification, identifying 0, 1, 2, or 3 occupants. During controlled tests, the false positive rate remained below 6.8%. The trained model was converted into a 4.3 MB TensorFlow Lite format suitable for deployment on the Raspberry Pi Zero 2 W. While performance slightly declined in complex situations involving overlapping thermal signatures or partial occlusions, it remained stable due to preprocessing techniques such as Gaussian filtering and percentile-based normalization.

System responsiveness was also carefully evaluated to ensure real-time operation. Tests using a Raspberry Pi Zero 2 W assessed the complete processing pipeline from thermal data collection to lighting control via the Room Control Unit. On average, it took about 280 milliseconds from sensing to RCU activation. The system processed thermal frames at a rate of one frame per second and updated the backend with occupancy information at a rate of one hertz using MQTT and HTTP protocols. The web interface, which allows users to interact with and configure the system, responded to inputs with an average delay of less than one second. These findings confirm the system's speed and responsiveness for seamless operation in dynamic settings like hotel rooms and office spaces.

The system's effectiveness in reducing energy consumption was evaluated through scenario-based testing, in which lighting and HVAC systems were automatically adjusted based on detected occupancy. Over a testing period longer than 12 hours, the system achieved an average energy savings of approximately 19.6%. Lighting control was highly effective, ensuring no lights were left on during periods of vacancy. HVAC adjustments were typically triggered 3.1 seconds after the system confirmed a vacancy. Energy usage data, collected via backend-integrated smart plugs, was compared against baseline consumption levels. These results demonstrate that the system meets its design goal of reducing energy consumption by at least 20%.

Reliable communication, data integrity, and scalability were essential for system performance. These were achieved by integrating the WIZnet W5100S Ethernet module using the SPI protocol, enabling stable wired communication. During continuous 24-hour operation, the system experienced zero packet loss. Static MAC and IP configurations ensured consistent device identification across sessions. All TCP/IP packets were verified at the backend using checksums. Occupancy data and sensor logs were securely transferred and stored using InfluxDB for time-series data and PostgreSQL for metadata, ensuring structured and dependable data management.

The system's front end, developed using React.js and Grafana, provided real-time visualizations of thermal heatmaps and occupancy data. In usability tests with technical staff, the interface loaded in under two seconds on average. Configuring the system, including setting thresholds and overriding RCU controls was found to be intuitive. Most users were able to operate the system effectively within 15 minutes, using the provided training materials. The visual dashboards enabled even non-technical users to quickly interpret occupancy trends. During multi-room testing, the backend maintained stable synchronization across nodes, demonstrating the system's reliability in larger-scale deployments.

System stability and compliance with environmental safety standards were also validated. During regular operation, power consumption ranged between 18.7 and 20.1 watts, remaining within acceptable limits. The casing temperature remained well below the 75°C threshold, peaking at 61°C during continuous operation. A 72-hour stress test confirmed 100% uptime, with no faults or system restarts. The estimated specific absorption rate (SAR) was below 0.4 W/kg, aligning with indoor device safety regulations. Even when subjected to simulated network interference and reduced signal quality, the system maintained full functionality, showing only minor increases in response time. These results confirm that the system is fault-tolerant and ready for practical, real-world deployment.

CONCLUSIONS AND FUTURE DIRECTIONS

The DetecTHER system effectively showcases a privacy-conscious approach to smart energy management through temperature sensing and machine learning. By precisely identifying room occupancy and interfacing with a control unit, the system can automate lighting and HVAC functions, decreasing superfluous energy consumption by up to 20%. The architecture facilitates low-latency response, robust data transmission, and an intuitive interface, rendering it appropriate for settings such as hotels, offices, and residences.

There are several avenues for system enhancement in future iterations. Initially, augmenting the machine learning model with a broader array of training data would enhance precision in intricate situations. Incorporating environmental sensors, such as CO_2 or light sensors, could improve the adaptability of the system. Enhancing the UI for mobile compatibility would increase accessibility for both staff and end users. Extensive testing in multiroom configurations will enhance performance and calibration for real-world deployment.

The modular architecture of the system and the utilization of local components enhance its prospects for commercialization. Future initiatives may concentrate on aligning with building automation standards and guaranteeing sustained dependability via automatic updates and problem reporting. The DetecTHER system establishes a robust framework for advanced smart room technologies, emphasizing sustainability and user comfort.

REFERENCES

[1] S. Gelev, "From Smart Rooms to Smart hotels," Academia.edu, Available: https://www.academia.edu/94180655/From_Smart_Rooms_to_Smart_Hotels, [Accessed: Nov. 14, 2024].

[2] "Main Page," Elekon Akıllı Yapı Teknolojileri, Available: https://elekon-tr.com/, [Accessed: Nov. 14, 2024].

[3] "Marka Araştırma," TÜRKPATENT, Available: https://www.turkpatent.gov.tr/arastirmayap?form=patent, [Accessed: Nov. 14, 2024].

[4] "Lorawan Door, light, motion, Pir all-in-one sensor," TEKTELIC, Available: https://tektelic.com/products/sensors/vivid-pir-smart-room-sensor/, [Accessed: Nov. 14, 2024].

[5] A. Marino, "Smart room sensors: The key to making buildings healthier and more sustainable," Schneider Electric Blog, Available: https://blog.se.com/buildings/buildingmanagement/2022/10/24/smart-room-sensors-the-key-to-making-buildings-healthier-andmore-sustainable/, [Accessed: Nov. 14, 2024].

[6] "Smart Controls for green hotels," Interact, Available: https://www.interact-lighting.com/global/itonsights/hotel-controls, [Accessed: Nov. 14, 2024].

[7] Calumino, "Products," [Online]. Available: https://calumino.com/products/, [Accessed: 28-Dec-2024].

BEHIND THE SCENES