Doorstep Entry Detection project report

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Abstract

Germany-based ELA Container GmbH is one of the leading suppliers of premium quality modular containers and it has spread over half a century with its business spread throughout Europe. In order to manage the digital transformation of the container industry, ELA formed a new company called 5ahead GmbH a subsidiary that focuses on utilizing IoT and AI to improve the utilization of the containers and satisfaction of the customers. The goal of this project under the consultancy of 5ahead GmbH is to build an elaborate Internet of Things monitoring system for occupancy and behavioral analysis in container units; the system shall include non-intrusive HC-SR04 ultrasonic sensors connected to an Arduino control unit. These sensors were chosen based on their reliability and effect on privacy which is a major issue with thermal cameras. The prototype generates information including the number of entry and exit rates which are very important for facility operation, energy consumption, and space utilization. This data is then housed and examined with the help of a Streamlit-based dashboard that shows current and past occupancy rates. This approach also reflects ELA's core values of being sustainably and operationally excellent and proves the ability of smart technologies to substantially raise the effectiveness of modular containers' utilization.

Keywords

Smart container, Ultrasonic sensors, Arduino, Occupancy rates

1. Introduction

One of the most distinguished manufacturers and suppliers of containers ELA Container GmbH operates today can trace its history to more than fifty years of its existence and is based in Haren (Ems) near the border to the Netherlands. Dealing strictly in luxury temporary homes/apartments and/or office spaces, ELA is famous for maintaining high standards of services consistent with Germany's quality assurance body. These modular containers are used in various industries such as in offices, particularly in construction sites, in schools and classrooms, and in makeshift diagnostic clinics during health emergencies. The number of companies that are part of ELA is over 470, with a total inventory amounting to more than 50,000 units, and ELA operates in several European countries, which proves excellent growth. This growth can not only explain how its workforce has doubled, but it also outlines how it has boosted its production capacity to meet rising production needs or demands.

With such dynamics and growing requirements for products and services in this area, ELA has created an innovation company 5ahead GmbH in the Gallery building on the territory of

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the Utwente campus. 5ahead GmbH rises to a central subject in ELA's approach, using the container industry to interrogate the possibilities of digital transformation. Being aimed at the optimization of the container sector and improvement of the customer experience using IoT and AI the role of 5ahead in the context of the drive for operational effectiveness and sustainability can be defined as rather strategic.

The current project, started by 5ahead GmbH, is designed to address certain issues that this organization, known as ELA, experiences when it comes to improving the utilization of container units. Since container spaces are used for various and changing requirements, the management and monitoring of these areas become important. Consequently, the project's primary objective is to design an effective method for occupant/behavior tracking, which plays a significant role in improving the work/functionality and the quality of the experience in smart containers.

The solution proposed in this work aims at establishing an IoT-based monitoring system with two ultrasonic sensors, namely HC-SR04, that is controlled by an Arduino unit. These sensors are carefully selected to be as accurate as possible and at the same time as least intrusive as possible, preventing privacy invasion as is the case with thermal cameras. This way the system will record the entry of people into the containers and the number leaving which is vital real-time information for several operational purposes. This setup also gives due consideration to the privacy of the users as well as blends easily into ELA's established smart container platforms.

The reasons for improving this monitoring capacity can be explained by the following: occupancy data are very useful when it comes to managing energy consumption because, with the help of various systems, occupancies can be controlled, thus influencing heating, ventilation, and air conditioning systems. Third, regarding space, it gives better planning and allocation of inner space, which is crucial as most of these containers have temporary and, generally, variable usage. All such improvements align with ELA's focus on sustainability and operational excellence in the organization.

Our envisioned solution is illustrated through the prototype in this project to show the feasibility of the approach. It encompasses a system set up to monitor the distance between the sensors and any object from there establishing whether anyone is gaining or losing ingress to a container. This information is then tracked accurately and encloses the sensor ID, measured value, and time of measurement and is saved as a JSON file for better compatibility with the other programming languages in order to improve data analysis the outcomes of self-powered sensors are noteworthy. After that, it creates another JSON file when certain entry or exit incidents occur with the time of day, the action whether it is an entrance or an exit, and the number of people in a container. In addition, all of this data is presented cleanly through a Streamlit-based dashboard that admits occupants at the entrance and gives real-time and historical data of the occupancy patterns graphed and summarized in neat metrics.

2. Ideal Solution

As discussed above in the introduction, we set out to improve monitoring capacity as occupancy data can be useful in further enhancing the smartness and usefulness of current ELA Container. Our ideal solution introduces a new sensor to ELA Container to track occupancy. This new sensor is displayed through the hand of a prototype (you can read more about this in section 3. Prototype). In the section below we discuss an ideal solution to the problem we set out to ”fix”.

2.1. High- Level Goals

An initial set of objectives have to be recognized. These are broad guidelines necessary to properly create goals for the projects. These are mostly broad strategic objectives.

- **Operational Efficiency**: Enhance the efficiency of container management using real-time occupancy data, enabling maintenance and resource allocation.
- **User Experience**: Improve customer and user satisfaction by providing a customized and optimized solution for each user (based on occupancy data).
- **Scalability**: Solution has to be scalable and usable, regardless of the amount, size or layout of the containers.
- **Privacy**: Occupancy data should be anonymous and privacy of customers should be ensured.
- **Security**: Customer data should be protected and stored adhering to GDPR standards.

2.2. Low-Level Goals

The low-level goals are there to aid with achieving the high level goals. These are more specific objectives with requirements that are measurable (time, cost etc.).

2.2.1. Objectives

- **Sensors**: Choose and implement sensors to recognize changes at door
- **Algorithm**: Create algorithm to process changes and track occupants (real time)
- **Data**: Store tracking data in format suitable for PostgreSQL integration
- **Dashboard**: Create Dashboard that utilizes data to track and visualize changes
- **Integration**: Integrate system in ELA Container and use data to improve usage of current smart technologies (air conditioning, heating etc.)

2.2.2. Requirements

- Should recognize changes at door 5x per second and be accurate regardless of how many people enter, simultaneously or at differing speed.
- Algorithm should be written using Python and not be resource heavy.
- Data accuracy and integrity should be ensured.
- Dashboard should be easy to use, update data close to real time (5 second delay margin).
- Energy consumption should be reduced by at least 10% using occupancy data.

2.3. Technology

Several technologies will be used, both in terms of hardware and software/architecture.

2.3.1. Hardware

- **Arduin Uno**: Handles connection to sensor and is able to run with python scripts for algorithm.
- **HC-SR04**: Ultrasonic sensor, used for detecting changes at door (measures distance between 2 points).
- **Breadboard & Wiring**: Connects Arduino with the sensors.
- **Case**: 3D-printed case for the sensors and Arduino.

Several things were taken into account, when deciding for these specific parts. The sensor was chosen for it's availability, cost and privacy related reasons. The Arduino was chosen for availability, flexibility and usability. Breadboard and wiring were choses out of necessity and the case was done out of showcasing and testing purposes.

2.3.2. Software

- **Streamlit**: Platform used for creation of dashboard
- **PostgreSQL**: Database system used for integration (currently used by ELA Container).
- **Python**: Language used to create algorithm

Several things were taking into account, when deciding for these platforms. Streamlit allows for connection to PostgreSQL and raw data files, has real-time capabilities and license is free. PostgreSQL was chosen as that is the currently used database platform for the ELA Container. Finally python was chosen as we have knowledge of this, is compatible and easy to integrate with the hardware selected.

2.4. Integration

To properly integrate the new solution with the existing systems of the ELA Container, a proper integration plan has to be created. This plan as we envision would take the following steps:

1. **System overview**: gain a organizational overview of current systems
2. **Testing & Documentation**: Testing the solution and documentation (for example for user guides or operational guides in case of maintenance)
3. **Installation**: Complete installation of new sensor into existing containers
4. **Maintenance**: Maintaining system and updating it if necessary.

2.5. Conclusion for Ideal Solution

This ideal solution aligns with GmbH's strategic goals, improving user experience, enhancing operational efficiency and creating value for customers. By leveraging existing IoT implementations (cooling, lighting, heating etc.) in combination with the ideal solution, GmbH's can create value for themselves and customers. It offers a greater more customized experience for customers, saving them potentially in power consumption and overall cost. Allowing GmbH's to position themselves better in an already competitive market and gain an further edge. To showcase these possibilities an actual prototype has been created and will be discussed in the next section.

3. Prototype

The aim of our project is to enhance the functioning as well as the efficiency of smart container buildings through some key aspects. The first one is striving to obtain precise occupancy measurement by keeping track of people entering and leaving a room, and also keeping up-to-date information about how full the room is at any given time. This data is important in optimizing energy efficiency as heating, ventilation, air conditioning (HVAC), and lighting systems can be adjusted based on actual occupancy in order to reduce energy usage and operational expenditures. Furthermore, we want to improve safety and security capabilities by providing accurate occupancy data which can help response teams during emergencies. Lastly, we look into ways of enhancing user comfort and experience by adjusting environmental conditions depending on occupancy levels thereby guaranteeing a comfortable living environment and better management of resources within the smart container. These targets together focus on making smarter, more efficient and user-friendly smart container buildings.

Technologies and Solutions Used

Our prototype required a very small budget of 20 euros which is one of the standout traits of our prototype, in which we can prove that sophisticated and functional solutions can be developed with a very small budget. The cost efficiency of technologies like the Arduino Uno and Ultrasonic sensors in parallel with their ease of integration and performance helped us make a prototype which is both economical and effective for implementation. This solution's cost-effectiveness is vital for scaling and applying it in smart container buildings as it decreases the cost of requirements, resulting in lowered risks and more benefits. It allows for enhanced occupancy monitoring and optimization without major financial commitment. The technologies we used are shown and mentioned below1 in further detail:

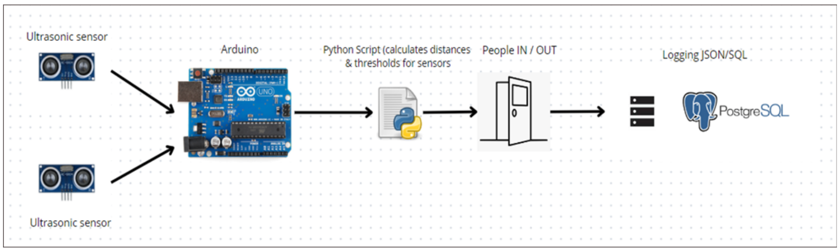

Figure 1: Prototype Structure Diagram

1.**Ultrasonic Sensors (HC-SR04):**
We chose to use two ultrasonic sensors for occupancy measurement for our project. We used the HC-SR04 sensors which use sound to determine the distance between the sensor and the closest object in its path. Ultrasonic sensors are essentially sound sensors, but they operate at a frequency above human hearing. The sensor sends out a sound wave at a specific frequency. It then listens for that specific sound wave to bounce off of an object and come back. The sensor keeps track of the time between sending the sound wave and the sound wave returning. We chose to use ultrasonic sensors over thermal cameras, which we initially planned on using, as it does not capture any visuals. We wanted to prioritize privacy, especially as this setup was intended to be implemented in a smart container where the occupants' privacy had to be fully respected. These sensors cost way less than thermal cameras, making it way more cost-efficient for our prototype. In our prototype, two ultrasonic sensors were placed at a distance away from each other to distinguish the direction of movement, i.e. if people are entering or exiting the container. We 3D Printed holders for these sensors to be easily adjusted according to the direction we wanted them to be in. By using these sensors we can provide a reliable and efficient occupancy detection system for the smart container, thereby leveraging occupancy data to perform smart practices in the container.

2.**Arduino Uno:**
The two Ultrasonic sensors are connected to the Arduino Uno. The Arduino starts out by transmitting a trigger signal and waits for an echo signal to be received by the HR-SC04 sensors. We chose to use the Arduino Uno for its simplicity, cost-effectiveness, and versatility. This microcontroller offers sufficient processing power for our prototype, memory, and connectivity options to deal with sensor data and to execute algorithms. The microcontroller's affordability and compatibility made it the ideal microcontroller board for our prototype which would contribute to the efficiency and effectiveness of our occupancy detection solution.

3.**Bread Board and Wiring:**
We used a breadboard and breadboard jumper wires to attach the sensors to the Arduino Uno. This allowed us to make easy adjustments during the development phase of the first version of the prototype that helped us make easy adjustments if something did not go as planned and helped with rapid testing when we wanted to check the data being sent by the sensors. Although we plan to solder the sensors directly to the board at the later stages of the prototype development, as it is more reliable and provides a more secure connection thus not disturbing the flow of data. As this is more important in real-world applications where consistency and robustness is crucial.

Algorithm:
The algorithm monitors the ultrasonic sensors' measurements to accurately track people entering or exiting the container, ensuring precise occupancy counts. It operates in stages shown in the figure2, initially detecting if a person triggers the first sensor and then confirming movement through the doorway by checking the second sensor within a time frame of 2 seconds. The algorithm can be explained using the flow diagram we constructed below.

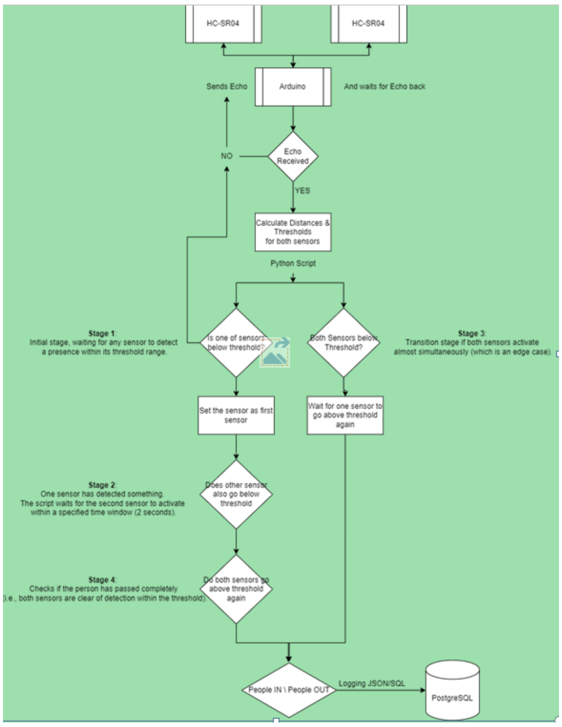

Figure 2: Algorithm

The process starts with the Arduino transmitting a trigger signal as explained before, if it receives an echo back the system proceeds to use predetermined thresholds and distances for both sensors using a Python script. If one of the sensors threshold's range is between the upper and lower limit, it detects presence, then it is set as the first sensor. If both the sensors go out of the threshold range this means that the subject is moving through the doorway and is not in the vicinity of the sensors, but this shall happen within a specified time frame of 2 seconds. So When there is a low threshold on the first sensor which we could label as entry and the second sensor as exit, we could determine when the subject is exiting or entering. After the subject crosses the door, the system checks if the subject has completely passed through by checking the thresholds of both sensors. If both sensors go above or below the threshold range again, it confirms that the subject has fully entered or exited the container. This data includes five measurements per second with both the sensors measuring in centimeters while the time measurement and the measurement values are stored in JSON format for easy manipulation and integration with other systems in the smart container which makes it highly scalable. This data is then logged into PostgreSQL for later analysis. The analysis of data is then visualized using a dashboard which shows the count of people in the container versus the time which facilitates analysing the current occupancy of the container.

GitLab repository of our project: https://gitlab.utwente.nl/s2001403/tno-high-rise

4. Conclusion

The project led by 5ahead GmbH has developed an IoT-based monitoring system for ELA Container GmbH's modular units. This system utilizes HC-SR04 ultrasonic sensors with an Arduino unit, proving to be deemed most important in identifying the number of people entering and exiting the containers. This provides key data on energy consumption and space efficiency which is useful for improving service operations by adjusting features such as temperature and lighting settings in consonance with the occupancy level, which will result in user satisfaction and energy conservation.

The advantage of the system is an opportunity to exclude such invasive technologies as cameras in connection with privacy issues, the interoperability of the system with other existing containers to enhance their performance, and the fact that it is a rather compact device. Furthermore, those sensors operate at any illumination level, require a low power supply, and are rather cheap, therefore ideal for large-scale deployment across multiple containers.

However, the system currently struggles when multiple people are detected within the reach of the sensor, the occupancy counts may be inaccurate. Sensors also struggle to distinguish people from other objects such as luggage which may be mistakenly counted as a person by the system. To increase the system's reliability, it is probably useful to try placing the sensors properly around the frames of the doorway to get better data; it could also be useful to incorporate more sensors that can provide different angles of observation in this domain, such as height sensing to differentiate between kids and grown-ups or objects.

Some desirable improvements in the future may lie in elaborating on these aspects, using sensor types beyond the ones mentioned in this paper, and potentially applying machine learning to differentiate between kinds of entries and exits. Further improvement in the studies of placement and usability of sensors will also be important in tackling the mentioned limitations and boosting the efficiency of this feasible IoT monitor platform.

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