Crowd Detection During Indoor Events Using FSR Sensor With Microcontrollers

Crowd detection and monitoring
Abstract

Overcrowding during indoor events can be risky, in-case of any kind of a hazard such as fire. This solution address this by providing real-time crowd detection solution using Force-Sensing Resistor (FSR) sensors, referred sensor (IR) and microcontrollers. The solution needs to offer accurate data in real-time to the event managers including number of people and entrance rate to help when and if the event areas will be overcrowded, thereby enhancing event safety and decision-making. This thesis indicate that the system offers essential real-time data for event safety with an accuracy of 87.25%. These data will assists event managers in making informed decisions to avoid the risks of overcrowding. This thesis evaluates the effectiveness of our system in comparison to other systems, discussing what we’ve learned, suggest possible improvements, and talk about whether our system could be useful in real-world indoor events.

Keywords

Crowd Management, Indoor events, Microcontroller, Sensor, detection, monitoring, Electrostatic discharge ESD, force-sensing resistor FSR
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1 Introduction

Crowds are a gathering where individuals come together, creating a collective presence. Crowds can vary in size, which can lead to problems at certain point. Crowds can form for events, activities, or shared cause. High density crowds can turn into a potential hazard, where unforeseen events such as fires may threaten safety. This is where the idea of "crowd detection and monitoring" comes into play. It’s like having a helper that keeps an eye on how many people are there, where they are, and how they’re moving.

Managing crowds indoors can be challenging as people move in different ways. The idea is to create a tool that helps the people in charge (organizers) make quick and smart decisions based on what’s happening in real-time. For example the Friday prayer at a mosques. In some mosques there is the problem of overcrowding that made the organizers start to shut their doors at some point and keep people outside, while other mosques have plenty of space left. This is a problem for Muslims as Friday prayer is part of one of the five pillars in Islam and is obligatory for Muslims. To address these kind of challenges effectively, the system must deliver accurate, real-time data, assisting organizers in efficiently managing crowd dynamics. Additionally, it should be both cost-effective and straightforward to deploy, ensuring that any event organizer can implement the system seamlessly. Equally important is not invade attendees privacy to maintain a trustful relationship between event organizers and attendees.

This thesis will discuss related works in the field, elaborate on the processes and rules guiding this design, outline the design and implementation procedures of the proposed device, and present experimental results in comparison to alternative methods for crowd detection.

1.1 Design Objectives:

- **High Accuracy:**
  Accuracy is essential in our device’s design, as it directly impacts the device purpose for event organizers. The device needs to be designed to accurately track crowd density in the event, providing accurate data crucial for decision-making during events.

- **Low Latency:**
  The system need to have low latency in data processing and transmission, which is essential for
keeping organizers updated within real-time. This urgency allows for fast response to changes in crowd dynamics, ensuring that any necessary adjustments will be made to event management can be made quickly and effectively.

- Privacy Considerations:
In terms of privacy, the device needs to be designed to respect the attendees privacy. It focuses solely on providing the number of individuals entering or exiting, without collecting or revealing any personal identifiers. This approach prioritizes privacy, making the device suitable for most events environments.

- Ease of Deployment and Cost:
There are many factors to look at for ease of use such as flexibility and simplicity with minimal impact on the existing infrastructure. The device should not make a huge modifications to the environment around it, particularly for temporary events. It should be a straightforward setup, enabling quick deployment without the need for specialized skills. Furthermore, the cost should be capped at 2000 SEK to ensure affordability for small event venues and organizers, without giving up on functionality.

1.2 Related Work
Crowd detection is an ongoing research topic where a variety of technologies have been proposed, such as Ultrasonic sensors[1], WiFi[2][3], Ultra wide band (UWB) radar sensors[4], LIDAR [5] and Camera[6][7]. However each of these technologies have it is own limitations and strengths. Camera based tracking requires a clear view of the target such as in this study [6] implemented a vision-based people counting system using existing surveillance camera footage which achieved an accuracy of 82.76% in less crowded conditions and an overall accuracy of 66.17% over extensive testing. In addition, this paper [7] evaluates various vision-based algorithms for people counting, with the highest accuracy being 82.76% using Histogram of Oriented Gradient methods during a specific scenario but with a high response time of 87 seconds, demonstrating the lacking of existing camera based crowd detection methods.
Also, This paper [4] present IR-UWB radar sensor approach to crowd detection inside of an
indoor room corner which present an accuracy of 93.6%.

And then, there is Lidar as this study [5] revealed that the integration of SVM into head-shoulder detection algorithms significantly improves people counting accuracy in crowded corridor scenarios, achieving an impressive accurate rate of 95.5%.

Moreover, the paper MOCUS: Moving Object Counting Using Ultrasonic Sensor Networks[1] showed a 90% accuracy rate in counting and motion direction analysis, where the experiment was conducted in a lab with a controlled environment. The results shows the potential of ultrasonic sensor networks in crowd detection.

Lastly, This paper [2] presents a smartphone-based people counting system that leverages crowd sourced WiFi signal data. The experiments were conducted in some lecture rooms when there were a number of students talking, sitting or walking around. This system offers an innovative approach to accurately estimate the number of people in an indoor area with an accuracy up to 93% without the need for additional hardware installations.

Existing crowd management solutions have shown commendable accuracy in various studies. However, these technologies have their limitations, particularly in privacy concerns. Such as cameras and WiFi systems can raise some privacy issues with the data that could be collected. Also, the higher latency with the need for higher process power for camera based system[7] which would mean even higher cost. Furthermore, the complexity of the setup of these devices, as they need to be installed on the ceiling, above the entrance or on high corners, with the correct angle and for some like LIDAR with a reflector at the right angle.[5].
<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic Sensors</td>
<td>Employs a three-node sensor cluster installed above the entrance. One node functions as the ultrasound transmitter, and the other two serve as receivers.</td>
</tr>
<tr>
<td>WiFi-Based System</td>
<td>Leverages existing WLAN infrastructure. It operates by analyzing fluctuations in RSS distribution every second to detect changes in the number of people.</td>
</tr>
<tr>
<td>UWB Radar</td>
<td>Utilizes IR-UWB radar technology to emit impulse signals and receive signals reflected back from people and objects, forming patterns that indicate crowd size and distribution.</td>
</tr>
<tr>
<td>Camera-Based Monitoring</td>
<td>Analyzes 1080p video footage frame by frame using the YOLOv3 model pre-trained on the COCO dataset for people detection and the Deep SORT algorithm for tracking.</td>
</tr>
<tr>
<td>LIDAR Technology</td>
<td>Uses a laser and a mirror reflection device for double-plane scanning. Captures pedestrian profiles with LIDAR and employs a head-shoulder feature based algorithm for detection and counting.</td>
</tr>
</tbody>
</table>

Table 1: Overview of Different Systems for Crowd Monitoring

1.3 Problem Formulation:

Addressing these concerns, this research proposes a crowd detection system specifically designed to overcome the privacy and deployment challenges of current technologies without giving up on accuracy or low latency. Our system uses Force-Sensing Resistors (FSR), Infrared Sensors (IR) and microcontrollers to offer a easy-to-deploy, cost effective, privacy-preserving solution for real-time crowd detection.
1.4 Aim and Research Questions:

- What are the accuracy levels achievable with the proposed crowd management system, and how do they compare to existing methods?

- What are the testing conditions that could impact the system’s accuracy in detecting crowd density?

- What are the potential limitations and challenges associated with the implementation of the crowd management system in real-world scenarios?

1.5 Scope and Limitations:

Scope:

- **Primary Focus:** The study focuses on the development and efficacy of a crowd detection system using Force-Sensing Resistor (FSR) sensors and microcontrollers, specifically for indoor event scenarios.

- **Application Context:** The system is designed for indoor events, with an emphasis on privacy.

- **Technological Implementation:** It looks into the utilization of FSR and Infrared (IR) sensors in conjunction with microcontrollers.

Limitations:

- **Controlled Testing Environment:** The experimental testing of the system was conducted in controlled settings, which may not entirely replicate the complexities of real-world scenarios.

- **Participant Diversity:** The testing involved a limited number of participants, lacking a wide range of diversity in size and weight, such as children, plus-size individuals, people with disability and elder people with walkers.

- **Footwear Variability:** All tests were conducted with participants barefoot, not accounting for the varied impact of different types of footwear in practical applications.

- **Budget Constraints:** The prototype faced certain limitations due to budgetary constraints and the hand-working skills of a university student, impacting the device’s durability as the FSR sensors may degrade over time with extensive use.

- **Protocol:** The test protocol required participants to not stand still on the device which subtracted the possibility of people triggering the device with both feet.
1.6 Target Group:

Event Organizers and Venue Managers: specifically those managing indoor events such as conferences, concerts, sports events, and religious gatherings. The system provides these professionals with real-time data on crowd density and movements, enabling them to make informed decisions to prevent overcrowding and enhance attendee safety.

1.7 Outline:

This thesis is organized as follows. Chapter 2, discusses the methodological framework, research methods, and ethical considerations involved in the development of the crowd detection system using FSR sensors and microcontrollers. Chapter 3 provides a detailed account of the hardware and software implementation, including a comprehensive table outlining each component’s function and role in the system. Chapter 4 describes the experimental setup used to test and validate the crowd detection system, as it shows the data results per trial and statistical analysis of results. Chapter 5 presents an analysis of the experimental results, discussing the effectiveness, accuracy, and practicality of the system. It also explores how the system meets the initial objectives and compare it to other systems. Chapter 6 concludes the thesis by summarizing the key findings and contributions of the study. It discusses the broader implications for crowd management during indoor events and outlines potential avenues for future research and development in this field.

2 Methodology

Methodology serves as the backbone of the study, meticulously crafted to ensure precision and validity in our findings. This study adopts an experimental approach, the details of which will be presented in the subsequent sections. The significance of a structured experimental approach cannot be overstated. We aim to provide empirical insights that are both reliable and replicable, thereby enhancing the robustness and credibility of our findings [3]. The thesis seeks to leverage crowd detection system to proactively address overcrowding concerns, by Testing the capability of the FSR-based system to accurately track the number of individuals entering indoor areas.
and detect the direction of movement of individuals and distinguish between entries and exits. This involves the monitoring of overall the crowd size, the distribution of individuals within different spaces, and helping with the identification of potential crowd-related challenges. A key consideration in this is assessing the FSR sensor ability for precise and accurate crowd detection. Additionally, we aim to evaluate the sensors’ ability to provide the data with low latency to ensure real-time information transmission. Moreover, we will utilize a combination of IR and FSR sensors to accurately determine the direction of people’s movement, effectively detecting whether individuals are entering or exiting a specific area. Not to mention, the data need to not include identifying data.

2.1 Experimental Design:
Our study employs a controlled experimental design to evaluate the performance of the FSR-based crown detection system. This design allows for the systematic manipulation of specific variables and the observation of their effects on the device’s performance.

2.1.1 Independent Variables:
- **Total Number of People Passing By**: We will vary the number of individuals passing through the detection area to assess how different crowd sizes impact the device’s performance.
- **Environmental Factors**: This includes variables such as lighting conditions, ambient noise, and temperature, which might influence the device’s functionality.
- **Number of Trials**: This experiment will test the device through 10 trials and each of 100 total entry.
- **Variation in Crowd Density**: Different scenarios to simulate various crowd dynamics.

2.1.2 Dependent Variables:
- **Device Accuracy**: Measured by the correctness of the count of people entering or exiting the room.
- **Device Latency**: Assessed by the time taken for the device to register and thesis an entry or exit.
- **Device Precision**: Evaluated by the device’s ability to consistently provide accurate counts across multiple trials.

### 2.1.3 Hypotheses:

The device will detect the number of people moving in or out of the room with an accuracy above 90%, regardless of crowd size or environmental conditions considering it will be indoor without much of environmental limitations. Also, the device will demonstrate low latency of 24ms providing real-time information while maintaining the high accuracy and precision of +90%, comparable to other crowded detection systems while upholding integrity by not invading attendees privacy.

### 2.2 Experiment Procedure:

The experiment will be conducted in a controlled environment. The device’s accuracy, latency, and precision will be calculated and compared against other systems which been tested in similar settings. Manual and finger ring counter will be used for comparison with the proposed system detection results.

**Experiment Set Up:** The experimental device, measuring 1 meter in width and 25 cm in length, will be positioned on the ground at the entrance. Accompanying this, IR sensors will be placed on the side, spaced 8 cm apart, to optimally capture the movement of individuals passing by.

**Case Variation:**

Case 1: Participant entering individually.

Case 2: Participant entering in a group.

Case 3: Participant entering in an irregular pattern (sometimes individually and sometimes in a group).

**Experiment Repetition:**

Number of Trials: 10 trials.

Total Entries/Exits per Trial: 100 entries/exits.

**Number of Participants:** 10 individuals.
2.3 Data Collection and Analysis:

2.3.1 Type of Data Collected:

- Crowd Detection Data: This includes information on number of entries into the specified indoor area, including timestamps and total headcount. The data will be collected through direct observation.

- Performance Metrics: Metrics related to crowd detection accuracy, precision, and response time will be gathered. These metrics will serve as key indicators of the system’s performance.

2.3.2 Data Collection Methods

- Observation: Data will be collected through direct observation of the controlled testing environment. This method ensures real-time monitoring and accurate recording of crowd behavior. It will ensure precise data collection, minimizing potential inaccuracies that may arise from automated sensors during testing.

- Sensor-Based Data Collection: Sensors collect various types of data from the testing. This will include the number of people entering or leaving and the latency of data reception. The data will be displayed on a serial monitor using Arduino IDE and a webpage on a local host.

2.3.3 Data Analysis Techniques

Where True positive occurs when individuals pass by the device and it correctly detects and counts them.

True Negatives in the context are meaningless as the device is designed to detect if someone passed by, not if someone did not pass by.

False Positives occur when the device mistakenly counts an individual. This can happen when someone passes by and the FSR sensor inaccurately counts them as two people, possibly due to overlapping pressure signals or sensor sensitivity issues.

Lastly False Negatives occurs when someone passes by the device, but it fails to detect and count them.
- **Accuracy**: The following formula will be used to calculate accuracy:
  \[
  \text{Accuracy} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Positives} + \text{False Negatives}}
  \]

- **Precision**: The following formula will be used to calculate precision:
  \[
  \text{Precision} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Positives}}
  \]

2.4 Strengths and Limitations

In assessing the effectiveness and implementation of both our design and testing, it is important to consider emerging strengths and limitations. This balanced assessment not only identifies the areas where our work excels but also acknowledges the challenges and limitations we faced, and gives us a general overview of the method.

**Strengths:**

- Customized algorithm development for accurate crowd detection.
- Real-time monitoring and response capabilities of microcontrollers.
- Low power consumption, contributing to energy efficiency and prolonged system operation.
- FSR sensor-based approach which potentially enable accurate results with fast response time.
- Ease of deployment, with the device being a Mat that just need to be laid on the ground next to the entrance/exit.
- Privacy with the device being unable to access or record any personal identifiers of people passing by.

**Limitations:**

- The testing phase of this project will be conducted in controlled environments with a smaller representation of a crowd.
- Testing conditions may not fully replicate real-world scenarios.
• Budget, as the device will be limited to be one meter wide with low durability.

• Time, the testing will be done to only one variation of the code and device design.

2.5 Ethical Considerations

- Privacy and Data Protection: Given the nature of crowd management systems, where it collects data on the attendees, a primary ethical concern is the privacy of individuals. It is crucial to ensure that the system does not collect or store identifiable data on the attendees. An extra step could be taken and ensure any data transmission is secure.

- Consent and Transparency: In cases where direct data collection from individuals is involved, informing them about the existence of the device would be essential. For example: adding a sticker next to it or outside the event entrance of having a detection device the same as there is sticker for security cameras.

- Compliance with Legal Standards: This system comply with GDPR (General Data Protection Regulation) as it is designed to respect attendee confidentiality by focusing solely on counting the number of individuals entering or exiting without collecting or revealing any personal identifiers, minimizing the collected data.

3 Hardware and Software Implementation

The implementation of both hardware and software is important in realizing the goals of our thesis. This section outlines the specifics of our hardware setup and the software that drives it, detailing each component’s role and integration into the overall system:
3.1 Hardware Implementation:

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>Arduino Uno Rev 4 WiFi will serve as the core processing unit. Chosen for its cost-effectiveness, ease of use as the Uno boards are the most accessible out of all Arduino boards, and built-in WiFi capability for data transmission.</td>
</tr>
<tr>
<td>Power Source</td>
<td>12V Wall adapter to provide a stable power supply for the Arduino Uno Rev 4 WiFi and connected sensors.</td>
</tr>
<tr>
<td>Active Infrared (IR) Sensor:</td>
<td>An IR sensor will be employed to detect the direction of movement of individuals and distinguish between entries and exits. Wiring will connect the IR sensor to the breadboard which will connect to the appropriate pins on the Arduino Uno for data acquisition.</td>
</tr>
<tr>
<td>FSR Sensor</td>
<td>Two layers of High Density ESD foam, each 6mm thick total of 12mm thickness in the center. Copper tape layers as conductive elements. Layer of High density foam on the top and bottom for durability and structure. Jumper Wires to connect the copper taps to the Arduino. Resistors to control the pressure on which the sensor will be triggered. Silicone to fuse everything together.</td>
</tr>
<tr>
<td>Copper Tape Slices</td>
<td>10 Vertically aligned copper tape slices, each 8cm wide and 22cm long. Positioned on the ESD Foam, separated by 8cm gaps. Wiring will connect the copper slices to the bread board which will connect to the Arduino on multiple analog inputs, allowing selective sensing of pressure points</td>
</tr>
<tr>
<td>Additional Components:</td>
<td>Breadboard to build a temporary circuit for the testing trials, jumper wires for the connection, resistors, and other basic electronic components for circuit connections.</td>
</tr>
</tbody>
</table>

Table 2: Hardware Implementation
3.2 Software Implementation:

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino IDE</td>
<td>The Arduino Integrated Development Environment (IDE) will be used for programming the Arduino Uno Rev 4 WiFi. Arduino programming language (a variant of C/C++) will be utilized for code development.</td>
</tr>
<tr>
<td>IR Sensor Logic</td>
<td>A code will be written to interpret signals from the IR sensor and the logic to determine whether an individual is entering or exiting will be implemented.</td>
</tr>
<tr>
<td>FSR Sensor Logic</td>
<td>A code will be written to interpret signals from the FSR sensor and the logic to determine which pressure point is being activated and to determine which pressure points should be disabled when others get activated.</td>
</tr>
<tr>
<td>Data Transmission:</td>
<td>WiFi capabilities of Arduino Uno Rev 4 can be utilized to transmit data to a designated server or a central monitoring system. Data can include information on crowd density and entry/exit rates.</td>
</tr>
<tr>
<td>Code Link</td>
<td>The Sketch Link Here</td>
</tr>
</tbody>
</table>

Table 3: Software Implementation

3.3 Justification for FSR Sensor-based Approach with Microcontrollers:

Microcontrollers offer a versatile platform that allows for tailored algorithm development and sensor integration, providing a level of customization essential for this project, just as utilizing multiple sensors that work together simultaneously such as the IR and FSR sensor used in this project.

The FSR sensor-based device’s capabilities enable immediate response to crowd dynamics, enhancing the system’s effectiveness in dynamic environments and enable accurate and precise results with low latency. Additionally, by using microcontrollers, which is based on the C++ language, it will ensure a fast and efficient implementation of the algorithm, further optimizing the system’s responsiveness.
4 The Experimental

For this experiment, the number of people passing through a designated indoor area was recorded. The process involved conducting 10 trials, each designed to count up to 100 individuals, to ensure the reliability and consistency of the data collected. During each trial, participants crossed the sensor device in various directions, both entering and exiting, and in different group sizes. This was to test the device’s capability to detect whether 1, 2, or 3 individuals were passing simultaneously. The Force-Sensing Resistor (FSR) sensor was detecting when individuals stepping on it, as well as the number of people doing so. Additionally, the setup included two Infrared (IR) sensors, placed 8 cm apart, to determine the direction of movement. The sequence of sensor activation provided info into whether an individual was entering or exiting the room. The accuracy of the device was evaluated by comparing the system counts against two benchmarks: people counting their numbers out loud while passing by and an observer using a counter while observing the serial monitor.

Figure 1: The FSR-Based System with IR Sensors

Figure 2: The Breadboard Diagram
4.1 Results

<table>
<thead>
<tr>
<th>Criteria/trial</th>
<th>Trial1</th>
<th>Trial2</th>
<th>Trial3</th>
<th>Trial4</th>
<th>Trial5</th>
<th>Trial6</th>
<th>Trial7</th>
<th>Trial8</th>
<th>Trial9</th>
<th>Trial10</th>
</tr>
</thead>
<tbody>
<tr>
<td>True Positive</td>
<td>96</td>
<td>96</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>94</td>
<td>94</td>
<td>93</td>
</tr>
<tr>
<td>False Positive</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>False Negative</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Accuracy</td>
<td>89.7%</td>
<td>88.8%</td>
<td>87.9%</td>
<td>87.9%</td>
<td>87.1%</td>
<td>87.1%</td>
<td>87.1%</td>
<td>85.4%</td>
<td>87%</td>
<td>84.5%</td>
</tr>
<tr>
<td>Precision</td>
<td>93.2%</td>
<td>92.3%</td>
<td>92.2%</td>
<td>92.2%</td>
<td>91.3%</td>
<td>91.3%</td>
<td>91.3%</td>
<td>90.3%</td>
<td>92.1%</td>
<td>90.2%</td>
</tr>
</tbody>
</table>

Table 4: Performance Metrics by Trial

The table above demonstrate a gradual decrease in the numbers after each trial, indicative of material degradation due to the absence of proper protective measures for durability. On another note, the data are encouraging and suggest that the FSR sensor-based devices has the potential to provide effective results in real-world applications.

Statistical Analysis of Results:

\[
\text{Mean of Accuracy} = 87.25\% \\
\text{Mean of Precision} = 91.64\% \\
\text{Mod of Accuracy} = 87.1\% \\
\text{Range of Accuracy} = 4.2\% \\
\]

\[
\text{Standard Deviation} = \sqrt{\frac{\sum (x_i - \text{mean})^2}{N}} = 1.427\%
\]
5 Discussion

This study set out to explore and prove the effectiveness of FSR sensor-based devices in providing information of help in managing crowds during indoor events. Specifically, it aimed to showcase the accuracy, precision and low latency of the information provided by FSR sensors compared to other methods in this area.

![Accuracy of each System Chart]

Figure 3: Comparisons with other crowd detecting systems ultrasonic[1], WiFi[2], Radar[4], LIDAR[5], Camera[7]

5.1 Comparisons

The first objective of this thesis is to compare the FSR-based device with other technologies across various criteria, including accuracy, precision, and latency. However, due to the lack of detailed information on many of these criteria in the existing resources, the comparison will primarily focus on accuracy, as it is the most critical factor. Accuracy is crucial for ensuring reliable data on crowd sizes and movements, which is essential for effective crowd management, safety, and security. Accurate information helps in making informed decisions, especially dur-
ing emergency situations or large public events.

As we can see in figure 3, the FSR sensor-based system has shown a commendable accuracy rate of 87.25% close to the level of the other systems. Furthermore, the other systems were experimented on similar settings. For instance, camera-based systems were evaluated in a lab setup, with cameras strategically positioned to face the entrance while still having a low accuracy of 82.76%, as detailed in [7]. Meanwhile, ultrasonic sensor systems were tested in a lab with sensors mounted on the ceiling at a height of 2.5 meters [1], and radar-based systems were positioned in a corner of a 5x5 meter indoor room to monitor the number of people present [4]. Other systems were examined in more realistic settings; for example, LIDAR-based systems were evaluated in a corridor with a predefined number of 300 pedestrians [5], and a WiFi-based system was implemented in a university classroom, demonstrating its practical application in real-world environments.

This validates the system’s effectiveness, affirming its ability to deliver results comparable to those of other systems [3].

When considering the most suitable system for indoor events, various factors come into play, including accuracy, latency, and privacy implications. The camera-based system, though comprehensive, falls short in accuracy and complex to set up, requiring an elevated position and optimal angle. Additionally, it raises significant privacy concerns. The radar-based system, while free from privacy issues and offering reasonable accuracy, requires professional installation, a requirement shared with the ultrasonic sensor-based system with accuracy of 90% [1].

In contrast, the LIDAR-based system presents the most challenging deployment, needing precise positioning and angling of reflectors [5]. However, it excels in accuracy, reaching up to 99% in certain tests, though generally averaging 95.5% [5], the highest among the systems. The WiFi-based system emerges as the easiest to install with a good accuracy of 93% [2]. Despite its potential privacy issues due to its reliance on connecting to individuals’ smartphones, it remains a good system when privacy is not a concern.

Finally, the FSR-based system stands out as a well-rounded option. It aligns closely with the experimental goals, offering ease of deployment (simply laying it on the ground with an adjacent wall for the IR sensor), low latency, and no privacy issues with it is inability to collect identifying data. However, it falls slightly short of the desired accuracy threshold, achieving
87.25% rather than the +90%.

5.2 Result Discussion:
The experimental results demonstrated that this system provide good balance between accuracy, precision and response time, indicating a potential for deployment in real word scenarios such as the one that inspired this thesis, The weekly Friday Muslims prayer. The FSR sensor-based device ease of deployment prove to be of important significance for events with it is simplicity and flexibility as all you need to do is lay the FSR sensor-based device, make sure to have good adhesion to the ground and setup the IR sensor on the wall next to it. Additionally, the compact size and low power requirements of microcontroller boards facilitate easy integration into various environments.

Answering the second research question: What are the testing conditions that could impact the system’s accuracy in detecting crowd density?

Another crucial aspect to consider involves the testing environment, where acknowledging specific limitations we encountered is essential. Initially, our participant pool was limited to only 10 individuals, an attempt to simulate crowd conditions in a controlled setting. However, this group lacked diversity in terms of size and weight, as the test did not include children or plus-size individuals.

Answering the third and last research objective: What are the potential limitations and challenges associated with the implementation of the crowd management system in real-world scenarios?

All tests were conducted with participants barefoot, a condition that differs from real-world scenarios where individuals are likely to wear various types of footwear. Moreover, the testing protocol required participants to step onto the device with only one foot, which does not account for scenarios where individuals might step with both feet. This protocol overlooks the potential impact of people carrying or strolling additional items, such as a baby stroller - on the device’s readings - a variability that could significantly influence performance in practical deployments.

Regarding the prototype’s quality, there were some constraints due to budgetary limitations and the crafting abilities typical of a university student. As well as, several improvements
could be made to bring forth more accurate and precis results. For instance, enhancing the wiring between the copper layers and the ESD foam could significantly improve the sensor’s performance, while having better protection around the sensors. On a different note, there is more designs that could be tested such as testing with copper layers that are 5 cm wide instead of the current 8 cm could provide valuable data on optimizing the sensor’s accuracy. Additionally, modifying the code to align with the enhanced specifications could effectively address some of the testing limitations we faced, as well as potential real-world challenges that may arise.

6 Conclusion

In summary, this thesis study the effectiveness of FSR sensor-based device in managing crowds during indoor events. Through multiple experiments, this thesis shows that FSR sensor can serve as a viable tool for real-time crowd detection, offering a balance of accuracy, precision, and response time that is comparable to existing methods.

Overall, the FSR sensor-based device has shown a commendable accuracy rate of 87.25% and a precision of 91.64% in detecting crowd movements, close with the rest of the other systems, even though it did not reach the threshold. Not to mention, ease of deployment, and low power requirements of the FSR sensor-based system underscore its practicality for indoor event scenarios.

However, the study also acknowledges certain limitations for the FSR-based system, as the testing required the participants to not stand still on the sensor and only pass by normally. In addition, the trials were conducted in relatively brief intervals, which could impact the comprehensive assessment of the sensor’s capabilities. On the other hand, the versatility of microcontrollers opens a wide range of possibilities for further enhancements, specially when coupled with Artificial intelligence.

Moreover, the potential for real-world application of such a system is significant but face some challenges, as it can significantly degrade overtime with extensive use such as the proposed scenario of the Muslim weekly Friday prayer. Also, having uncontrollable elements such as people with special conditions passing by such as people using wheelchairs and or older people that use a walkers. Still, Its ability to offer quick and accurate crowd density data can greatly
aid event organizers in making informed decisions to ensure safety and optimal crowd flow. The privacy-preserving nature of the technology, which does not involve personal identifier data collection, also adds to its appeal.

In conclusion, this study is a proof for the ability of FSR sensor-based approach in providing valuable data for crowd management during indoor events. As it offers a promising direction for further research in this field, contributing to the safer and more efficient management of crowds in various indoor settings.

References


