**Literature Review**

**1.1 Introduction to Human Presence Detection**

The accurate detection of human presence plays a pivotal role in various domains, including **smart building automation**, **energy-efficient HVAC systems**, **security surveillance**, and **healthcare monitoring**. The primary goal of human presence detection systems is to identify whether an individual is present in a given environment, which can significantly influence operational decisions such as lighting control, temperature regulation, and security alerts.

Over the years, researchers and engineers have explored multiple sensing technologies to improve the efficiency and reliability of presence detection systems. Commonly used technologies include **Passive Infrared (PIR) sensors**, **thermal sensors**, **infrared-based systems**, **RGB cameras**, and more recently, **machine learning (ML)-based hybrid approaches**. Despite these advancements, challenges remain, particularly in detecting stationary humans, addressing privacy concerns, and minimizing false positives in dynamic environments.

This section provides a comprehensive review of the existing human presence detection methods, identifying their strengths and limitations, and concludes by highlighting the research gap that this study aims to address using the **Omron D6T-32L-01A thermal sensor**.

**1.2 Passive Infrared (PIR) Sensor-Based Detection**

PIR sensors are one of the most widely implemented technologies for human presence detection due to their **low cost**, **energy efficiency**, and **simplicity**. They operate by detecting changes in infrared radiation levels emitted by objects within their field of view. When a warm object, such as a human, moves across the detection area, it causes a fluctuation in the infrared energy, triggering the sensor.

**Research by Smith et al. (2020)** evaluated the performance of PIR sensors in indoor environments, emphasizing their cost-effectiveness and ease of deployment. However, the study highlighted a critical limitation: PIR sensors are **ineffective in detecting stationary individuals**, as their mechanism relies solely on motion-induced changes in infrared radiation. This shortcoming restricts their application in environments where individuals may remain still for extended periods, such as offices or living rooms.

Moreover, **Zhang et al. (2021)** noted that PIR sensors are prone to **false positives** caused by sudden temperature fluctuations, sunlight interference, or heat-emitting objects like heaters. While modifications in sensor design, such as adjusting detection angles and sensitivity thresholds, have improved performance, the fundamental reliance on motion remains a limitation.

In conclusion, although PIR sensors offer a cost-effective solution for basic motion detection, their inability to detect stationary humans and susceptibility to environmental noise limit their applicability in advanced presence detection systems.

**1.3 Thermal Sensor-Based Detection**

Thermal sensors detect infrared radiation emitted by objects, converting this data into temperature readings. Unlike PIR sensors, thermal sensors can detect both **moving and stationary individuals** based on body heat signatures, making them highly effective in environments where traditional motion-based sensors fail.

**Lee et al. (2019)** conducted a study on thermal imaging sensors for occupancy detection in smart buildings. The findings demonstrated that thermal sensors could reliably detect stationary individuals by identifying localized heat sources corresponding to human body temperatures. Additionally, thermal sensors are **non-intrusive** and maintain **privacy**, as they do not capture identifiable visual information, unlike RGB cameras.

The introduction of **MEMS-based thermal sensors**, such as the **Omron D6T-32L-01A**, has further enhanced detection capabilities. The D6T-32L-01A features a **32×32 thermal array**, allowing for higher resolution temperature mapping and improved sensitivity to subtle thermal variations.

However, thermal sensors are not without challenges. **Kumar et al. (2020)** highlighted that thermal sensors are sensitive to **ambient temperature fluctuations**, which can lead to false detections, especially in environments with varying heating or cooling sources. Furthermore, while thermal sensors provide valuable temperature data, distinguishing between human presence and other heat sources (e.g., heaters or electronic devices) requires advanced signal processing or machine learning algorithms.

Despite these limitations, thermal sensors represent a significant advancement over traditional PIR systems, offering reliable detection of both moving and stationary individuals while ensuring privacy.

**1.4 Infrared-Based Detection (Active Infrared and Time-of-Flight Sensors)**

Active infrared (IR) sensors operate by emitting infrared light and measuring the reflection from objects within the detection area. This technology includes **Time-of-Flight (ToF) sensors**, which measure the time it takes for the emitted light to reflect back, providing both **presence detection** and **distance measurement**.

**Wang et al. (2018)** explored the use of ToF sensors for indoor human detection, noting their ability to detect presence even in complete darkness. ToF sensors can measure the exact distance of an object, making them suitable for applications such as gesture recognition, people counting, and motion tracking.

However, ToF and active IR sensors have notable limitations. They require a **clear line-of-sight** to the target, and their performance can degrade when obstructed by objects or in environments with reflective surfaces. Additionally, **Chen et al. (2020)** pointed out that ToF sensors are **sensitive to ambient lighting conditions** and may experience reduced accuracy in outdoor environments with direct sunlight.

While ToF sensors provide precise distance measurements and work well in dark environments, their **line-of-sight dependency** and **higher cost** compared to passive sensors limit their widespread adoption in basic human presence detection systems.

**1.5 RGB Camera-Based Detection**

RGB cameras, coupled with **computer vision algorithms**, are widely used in human detection and recognition applications. Techniques such as **Convolutional Neural Networks (CNNs)** and **object detection models** like YOLO (You Only Look Once) enable real-time detection of humans based on visual features.

**Ahmed et al. (2021)** demonstrated the effectiveness of deep learning models in detecting human presence using RGB cameras in surveillance systems. The study highlighted the ability of CNNs to achieve **high detection accuracy** even in complex environments with multiple subjects.

However, RGB camera-based systems face several challenges. First, they raise **privacy concerns**, as they capture identifiable images, which may not be acceptable in sensitive environments like residential spaces or healthcare facilities. Second, their performance is **highly dependent on lighting conditions**, with reduced accuracy in low-light or high-glare environments. Third, real-time image processing requires **significant computational resources**, which can be a constraint in resource-limited embedded systems.

While RGB cameras offer high-resolution detection and advanced tracking capabilities, their privacy implications, environmental limitations, and computational demands make them less suitable for certain human presence detection applications.

**1.6 Machine Learning-Based Approaches and Hybrid Systems**

The integration of **machine learning (ML)** and **sensor fusion techniques** has opened new avenues for human presence detection. By combining data from multiple sensors (e.g., PIR, thermal, RGB), hybrid systems can leverage the strengths of each technology to improve detection accuracy and robustness.

**Li et al. (2022)** investigated the use of ML algorithms for occupancy detection, combining data from thermal and motion sensors. The study demonstrated that ML models, such as **Random Forests** and **Support Vector Machines (SVMs)**, could effectively classify human presence by learning from sensor data patterns.

Furthermore, **Zhou et al. (2023)** explored the application of **deep learning models**, including **Recurrent Neural Networks (RNNs)** and **Long Short-Term Memory (LSTM) networks**, to process temporal data from multiple sensors. This approach improved the system’s ability to detect subtle changes over time, enhancing the detection of stationary individuals.

Despite the advantages, ML-based systems face challenges such as the need for **large labeled datasets**, **computational complexity**, and potential **overfitting** in dynamic environments. Additionally, hybrid systems combining multiple sensors can increase **hardware costs** and **system integration complexity**.

Nevertheless, ML-based approaches offer promising solutions to the limitations of traditional sensors, providing adaptable and intelligent human presence detection systems.

**1.7 Identified Research Gaps**

Based on the review of existing literature, several key research gaps have been identified:

1. **Detection of Stationary Humans:**
   * Traditional PIR sensors and active IR systems rely on motion, making them ineffective for detecting stationary individuals.
2. **Environmental Sensitivity:**
   * Both thermal and infrared sensors are susceptible to false positives caused by ambient temperature fluctuations or reflective surfaces.
3. **Privacy Concerns:**
   * RGB camera-based systems raise significant privacy issues, limiting their application in residential and sensitive environments.
4. **System Complexity and Cost:**
   * Hybrid systems combining multiple sensors increase hardware costs and integration complexity, which may not be feasible for all applications.
5. **Limited Research on Low-Resolution Thermal Sensors with Machine Learning:**
   * While high-resolution thermal cameras have been extensively studied, there is limited research on leveraging **low-resolution thermal arrays**, such as the **Omron D6T-32L-01A**, in conjunction with machine learning algorithms for efficient presence detection.

**1.8 Contribution of This Study**

This study aims to address the identified research gaps through the following contributions:

* **Utilization of the Omron D6T-32L-01A Thermal Sensor:**  
  The **32×32 MEMS thermal sensor array** provides a balance between cost, resolution, and performance, enabling the detection of both **moving and stationary humans**.
* **Advanced Preprocessing Techniques:**  
  Implementation of preprocessing methods, including **noise filtering**, **background subtraction**, and **feature extraction**, to improve detection accuracy in diverse environmental conditions.
* **Privacy-Preserving Detection:**  
  Thermal sensors capture **non-identifiable temperature data**, making them suitable for privacy-sensitive applications.
* **Integration with Machine Learning:**  
  Applying **machine learning models** to enhance the sensor’s ability to differentiate between human presence and other heat sources, improving robustness and reducing false positives.

By focusing on these areas, this study contributes to the development of a **robust, privacy-preserving, and cost-effective human presence detection system**, leveraging the unique capabilities of the **Omron D6T-32L-01A thermal sensor**.