# Literature Review

## Human Presence Detection

Within the scientific fraternity, human presence detection (HPD) has been a topic of great interest, given that the applications of this domain transcend several use cases including energy management, security and surveillance systems, automation, and adaptive management in the face of climate change (Puurunen *et al.*, 2021). In particular, for surveillance and security systems within smart buildings, homes, and factories, human presence detection is crucial. (Doan *et al.*, 2024). As such, the use of device-free technology becomes imperative when an individual’s presence becomes infeasible, dangerous, or highly costly (Nanzer and Rogers, 2007). Therefore, improving the human detection accuracy of such technologies is a fundamental aspect of the system's performance. Henceforth, the option of adequate technologies for human perception has surfaced as an eminent area of contemporary research with a plethora of research focusing on the development of different sensor technologies and machine learning (ML) models as attempts to evade the shortcomings in the existing systems.

## Sensor Technologies for Human Presence Detection

***Passive Infrared (PIR) Sensors***

Concerning the accumulation of occupancy data, a diverse array of sensor technologies can be employed and each of them presents its own merits and shortcomings. Among the myriad of available sensor technology types, PIR sensors have been the focus of several scholarly works due to their cost-effectiveness, non-invasive dynamics, and simple nature (Shokrollahi *et al.*, 2024). In this sense, one of the research works has been done by Andrews et al. (2020) who developed a cost-effective way to detect stationary humans within indoor spaces thereby delineating a novel method to straddle the sensor on a mobile platform. Leveraging an artificial neural network (ANN), the study showcased an augmented scope of the sensor functionalities for detecting the occupancy parameters while presenting a 91% accuracy for the count estimates of the room occupation and a 93% accuracy in distinguishing human targets. Likewise, Doan et al. (2024) put forward a machine learning (ML), in particular, learning vector quantization (LVQ) based PIR sensor technology to improve human detection accuracy. By analyzing the functioning of the intelligent sensor in distinct environments within two distinct locations, the study authors made use of generalized LVQ (GLVQ) and generalized matrix LVQ (GMLVQ) to reveal detection accuracies of 86.1% and 89.25%, respectively thereby highlighting remarkable potential owing to the lesser computational costs of the technology (Doan *et al.*, 2024).

***Vision-based Sensors***

The technological shortcomings of PIR sensors including the lack of detection of static humans, sensitivity to sunshine radiations and airflow, and the sub-optimal distinction between humans and animals paved a pathway for alternative technology options such as vision-based sensors. In this regard, research work by Benezeth et al. (2011) suggested a vision-based system for HPD, through a video analysis mediated by a static camera, within indoor spaces. Involving three fundamental steps of detecting a change through a background model, tracking objects, and comprehending the nature of objects in the scene, the study reported a detection accuracy of 97% with numerous applications of the technology including occupancy detection, individual counting, and activity characterization including energy-efficient buildings, HVAC, and security (Benezeth *et al.*, 2011).

***RF-based sensors***

***Environmental sensors***

***Ultrasonic sensors***

***Wifi-Based Sensors***

Given that conventional vision-based approaches to human detection (HD) are assisted with several limitations including the absence of sensor flexibility and poor accuracy, non-intrusive methods to human presence detection have been the subject of recent research work. In particular, Mesa-Cantillo et al. (2023) present an approach to HD through the channel state information (CSI) of the Wi-Fi networks where the features within the time domain assist in HD. Through the use of the 802.11n standard, multiple-input multiple-output (MIMO) assisted with orthogonal frequency division multiplexing (OFDM) facilitates CSI data for each subcarrier, thereby allowing an average detection accuracy of 90% (Mesa-Cantillo *et al.*, 2023). Similarly, Shen et al. (2023) also employed CSI data from commercial wireless communication networks for device-free HPD through the use of a time-selective conditional dual feature extract recurrent network (TCD-FERN) within multi-room settings. Through the use of the dual-feature extraction recurrent network based on time selection serving to address the issues of feature attenuation and signal variation, the research work presents a higher detection accuracy of 97% with the use of a lesser number of Wifi access points (APs) (Shen *et al.*, 2023). In a recent attempt, Zhang et al. (2024) proposed a novel approach to HPD based on Wi-fi networks which constituted three phases including the pre-processing of CSI followed by feature extraction and classification. The research results report a high sensing accuracy of up to 99% with accurate and robust perception and HP owing to the signal models consonant to the varying states including an empty room, a room with a human, and a room with someone who recently moved (Zhang *et al.*, 2024). Despite the promising potential, the method presents limitations concerning a distinction between the detection of a single person or multiple people restricting the applicability of such systems (Mesa-Cantillo *et al.*, 2023).

***Thermal Sensors***

Given the extensive amount of work being done to develop economical yet highly accurate models for HPD, a promising approach in this regard is the use of thermal sensors. As such, Chuah and Teoh (2020) present the use case of a thermal sensor for the detection of stationary humans as a means of the intelligent control of electrical appliances within a smart home. The researchers made use of a calibration approach for adequate temperature threshold detection, and the bifurcation of the sensor area into various sections for accurate HD, allowing a reduction in electrical energy wastage and energy consumption.

## Machine Learning Models for Human Presence Detection

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