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RECOGNITION OF HUMAN PRESENCE AND BEHAVIOR FOR INTELLIGENT HVAC: COMPARATIVE ANALYSIS OF CNN MODELS ON RASPBERRY PI

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Abstract
Computer vision using CNNs on devices like Raspberry Pi enables accurate human presence detection for optimizing HVAC systems. Studies show over 90% accuracy and up to 40% energy savings with edge-deployed models. Successful integration requires balancing accuracy, speed, resource constraints, and privacy.

Keywords: computer vision, convolutional neural networks, intelligent HVAC systems, edge computing, Raspberry Pi

Introduction. Heating, ventilation, and air-conditioning (HVAC) systems account for a large share of building energy consumption – roughly 37% of primary energy usage in buildings, of which HVAC contributes around 40%. Traditional HVAC operations often assume maximum occupancy or fixed schedules, leading to energy waste by conditioning unoccupied or under-occupied spaces. Occupancy-driven climate control has been shown to dramatically improve efficiency: dynamic HVAC adjustments based on actual human presence can reduce energy usage by anywhere from 10% up to 40% in real-world implementations. This motivates the need for accurate, real-time detection of human presence and behavior in indoor environments. If an HVAC system knows when people are present, how many, and even what they are doing, it can intelligently adjust heating, cooling, and ventilation to balance comfort with energy savings [1, 2].

Precision of the system's diagnosis. To illustrate qualitatively, Figure 1 below shows an example output of a CNN-based people detector in the 'UNIHUB' for students in Almaty. The system identifies each person (pink boxes) and can count the total ("People: 12" in this instance). This kind of output can be converted to an occupancy count signal for an HVAC controller (e.g., if people > 0, turn HVAC on; if count is high, ensure adequate ventilation, etc.). Even a relatively small model can produce such detections given a clear view (fig 1).

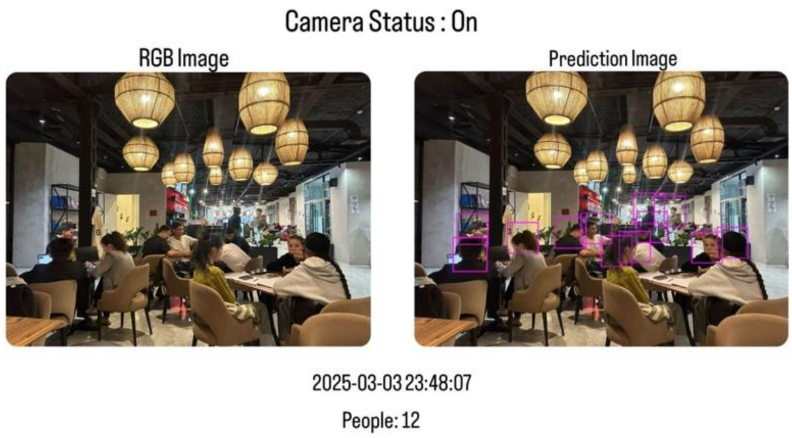

Figure 1 - example output of a CNN-based people detector

The system processes camera images to count people (12 in this instance) by detecting each individual (bounding boxes and labels overlaid). This information can then be used to control HVAC operations in the space. Performance comparisons show that lightweight CNNs like MobileNet-SSD and Tiny-YOLO deliver fast, sub-second inference on edge devices but may miss occluded or distant subjects in cluttered environments. Higher-complexity models, such as full YOLO, offer greater detection accuracy for small or partially hidden people yet operate too slowly without dedicated accelerators.

As a result, many implementations choose an intermediate solution—using models like YOLOv5/8-small—with some acceleration or reduced frame rates to balance speed and precision. Upgrading from Raspberry Pi 3 to Pi 5 leads to significant performance improvements, with the Pi 5 roughly halving inference times compared to the Pi 4 (e.g., 93 ms versus 209 ms for SSD). The Pi 5's new NPU can enable certain models to run in real time, providing further benefits for time-sensitive applications. Alternative platforms, such as the Nvidia Jetson series, outperform Raspberry Pi for running CNNs, although they require higher power consumption and are better suited for deployments with multiple cameras or strict real-time demands [3].

Energy efficiency studies indicate that while Jetson Orin may have high idle power draw, its rapid processing results in low energy per image, and pairing a Raspberry Pi with a TPU accelerator like Coral nearly matches this efficiency. Despite these advances, detection robustness challenges persist, as systems may undercount individuals when people are tightly packed or positioned near room edges, emphasizing the need for optimal camera placement.

In HVAC applications, occupancy detection—whether by simple binary status or through people counting—enables dynamic control strategies that can yield energy savings ranging from 5% to 40% while also enhancing comfort.

Collectively, these studies demonstrate that CNN-based systems on edge hardware can effectively support intelligent HVAC control, with future efforts aimed at addressing limitations and refining real-world deployments [4].

Conclusions. Convolutional neural networks running on edge devices have proven to be effective "eyes" for smart HVAC systems – they can see where the people are and how many, allowing climate control to be adaptive, efficient, and occupant-centric. While there are deployment challenges to work through, the combination of advancing AI algorithms and IoT hardware is steadily tipping the balance in favor of such intelligent, responsive buildings. With continuing research and development, we anticipate that vision-enhanced HVAC control.

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РОЗПІЗНАВАННЯ ПРИСУТНОСТІ ТА ПОВЕДІНКИ ЛЮДИНИ ДЛЯ ІНТЕЛЕКТУАЛЬНИХ СИСТЕМ HVAC: ПОРІВНЯЛЬНИЙ АНАЛІЗ МОДЕЛЕЙ CNN НА RASPBERRY PI

Анотація
Комп'ютерний зір на базі згорткових нейронних мереж (CNN), реалізований на пристроях типу Raspberry Pi, дозволяє точно визначати присутність людини з метою оптимізації роботи систем HVAC. Дослідження демонструють точність понад 90% та до 40% економії енергії при розгортанні моделей на edge-пристроях. Успішна інтеграція вимагає балансу між точністю, швидкодією, обмеженими ресурсами та конфіденційністю.
Ключові слова: комп'ютерний зір, згорткові нейронні мережі, інтелектуальні системи HVAC, edge-обчислення, Raspberry Pi

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