OCCUPANCY DETECTION METHODS

LEARN HOW OCCUPANCY DETECTION METHODS CAN BE LEVERAGED IN CREATING SMARTER ENVIRONMENTS

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softserve

Smart cities, buildings, and other smart strategies significantly rely on presence of humans and their quantity. This kind of human sensing is named occupancy detection. Occupancy detection requires body-mounted sensors, terminals (Wi-Fi, Bluetooth) in the pocket or ambient sensors (environmental) in a smart environment with sophisticated AI and ML algorithms to analyze the measurement results. Below, you can find descriptions of various ambient solutions that can be embedded into the environment.

VIDEO CAMERAS

Most building entrances and infrastructure objects have video cameras, these devices and others help foster occupancy detection. As an example, Analog Devices has developed Blackfin®, a low-cost and low-power embedded computer vision platform that has a smart motion sensing functionality.

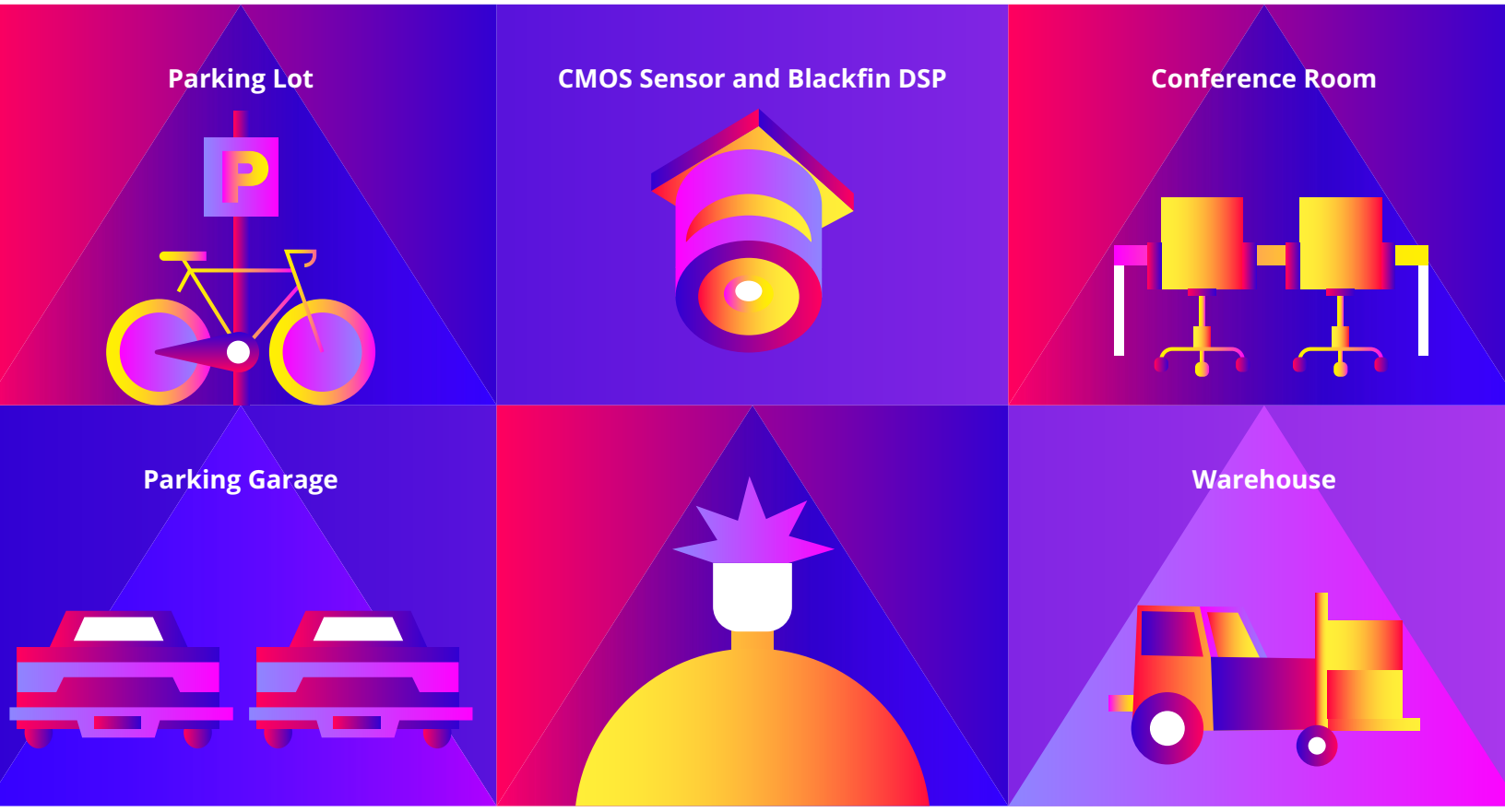
Illustration of system work

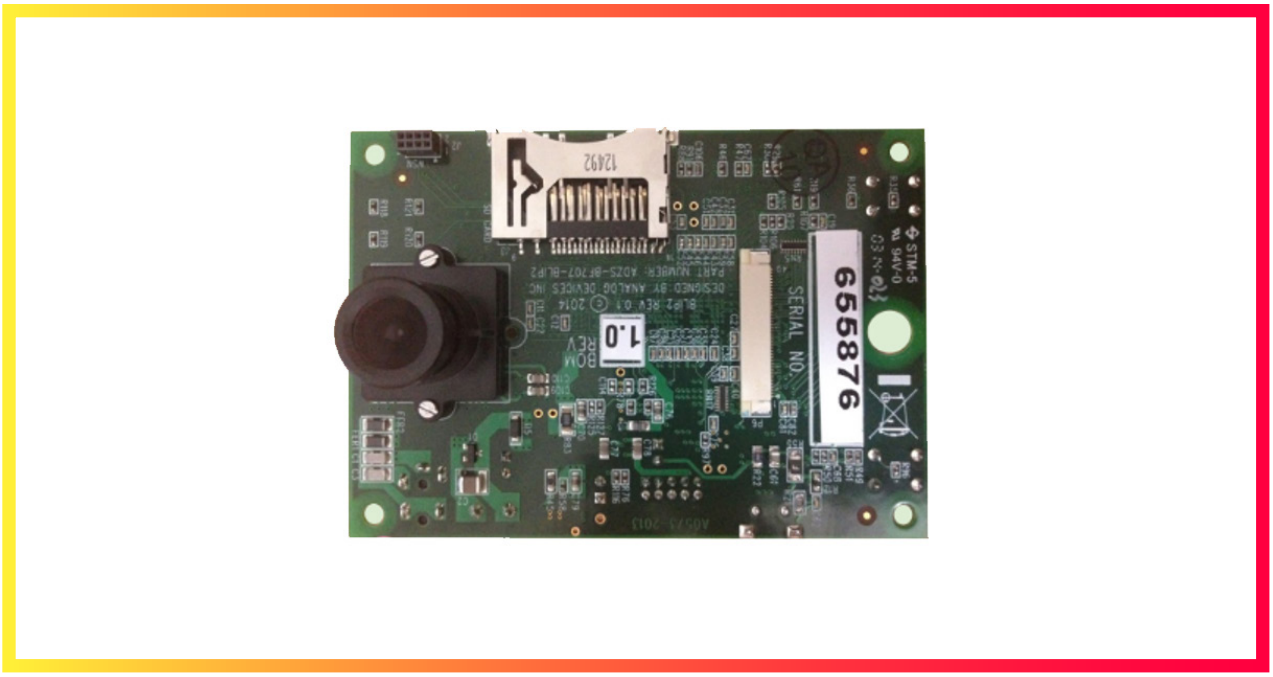
Pros

- Benefit from progressive progress in image/video processing and computer

Cons

- The quality depends on light conditions
- People usually change their behavior in front of cameras
- Easily used for user identification or privacy violation





Camera sensor

INFRARED (IR) CAMERAS (PYROMETERS)

Using IR cameras instead of RGB allows fixing certain privacy issues. It is hard to identify people on the IR video stream to use for compromising materials—even if a video is stolen.

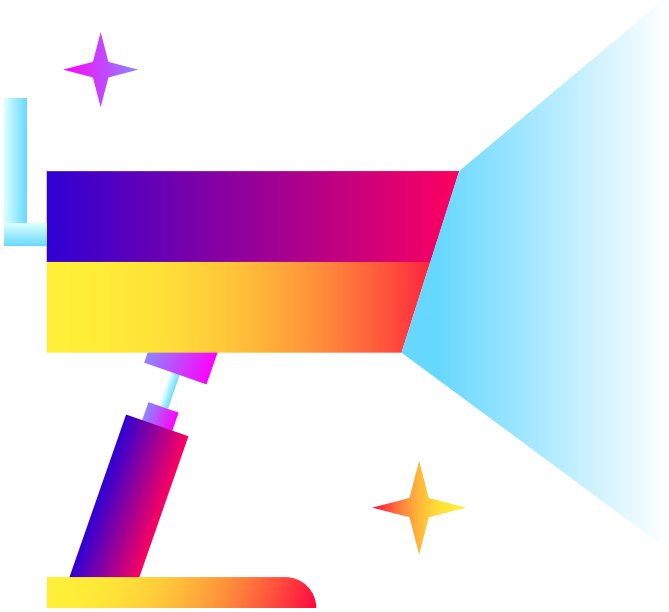
Sensor construction and recommendations of placement are described here.

Pros

- Do not depend on lighting conditions
- Allow tracking people's temperaturevi-sion, lowered pricing on HD cameras

Cons

- IR cameras are more expen-sive than RGB cameras



PASSIVE INFRARED (PIR) SENSORS

These sensors are commonly used for occupancy detection in alarms and light control systems. They are sensitive only to changes in infrared radiation (human motion, for example).

Pros

- Cheap, have a small form factor and low power consumption
- Provide only binary information about occupancy that makes them the best sensors from a privacy point of view

Cons

- Suitable only for occupancy detection
- Require a direct line of sight between a sensor and an occupant
- Not sensitive if people do not move
- Are influenced by thermal currents—hot coffee or tea, heating, ventilation, air conditioning systems, pets, etc.

ARRAY OF INFRARED SENSORS

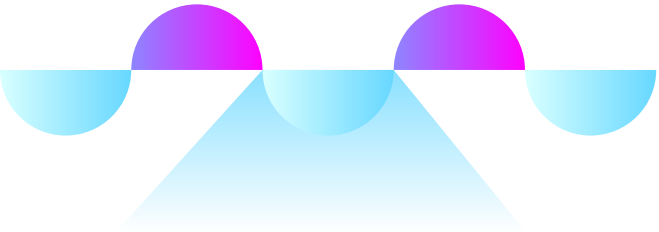
Placing several infrared sensors allows us to capture a temperature pattern and detect changes depending on how many people are in the room and their activity. In this work, authors placed infrared sensors at the doorways for counting the number of people inside rooms.

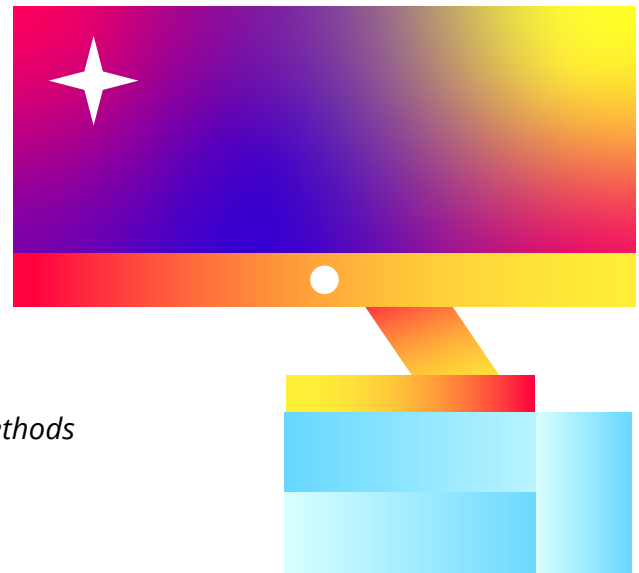
Pros

- Authors claim that their approach works without additional learning
- Allows detecting skin temperature

Cons

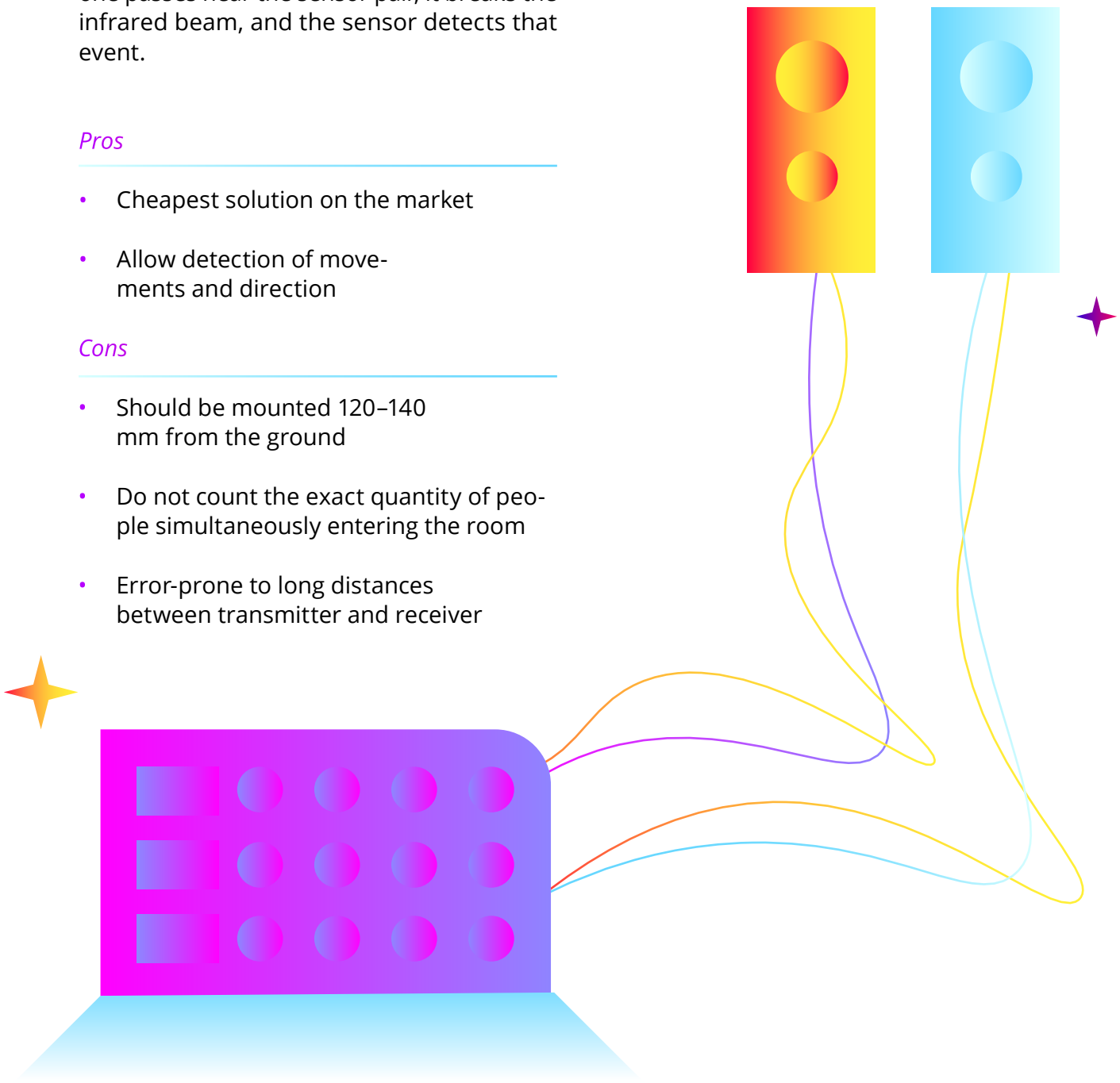
- Difficult to count the quantity of several people simultaneously entering a room through the same door
- Error-prone if distances are longer





BREAK-BEAM SENSORS

If an IR sensor is a passive solution, the break-beam sensor is an active one. It consists of a pair of devices – a transmitter of the infrared beam and its receiver. If someone passes near the sensor pair, it breaks the infrared beam, and the sensor detects that event.

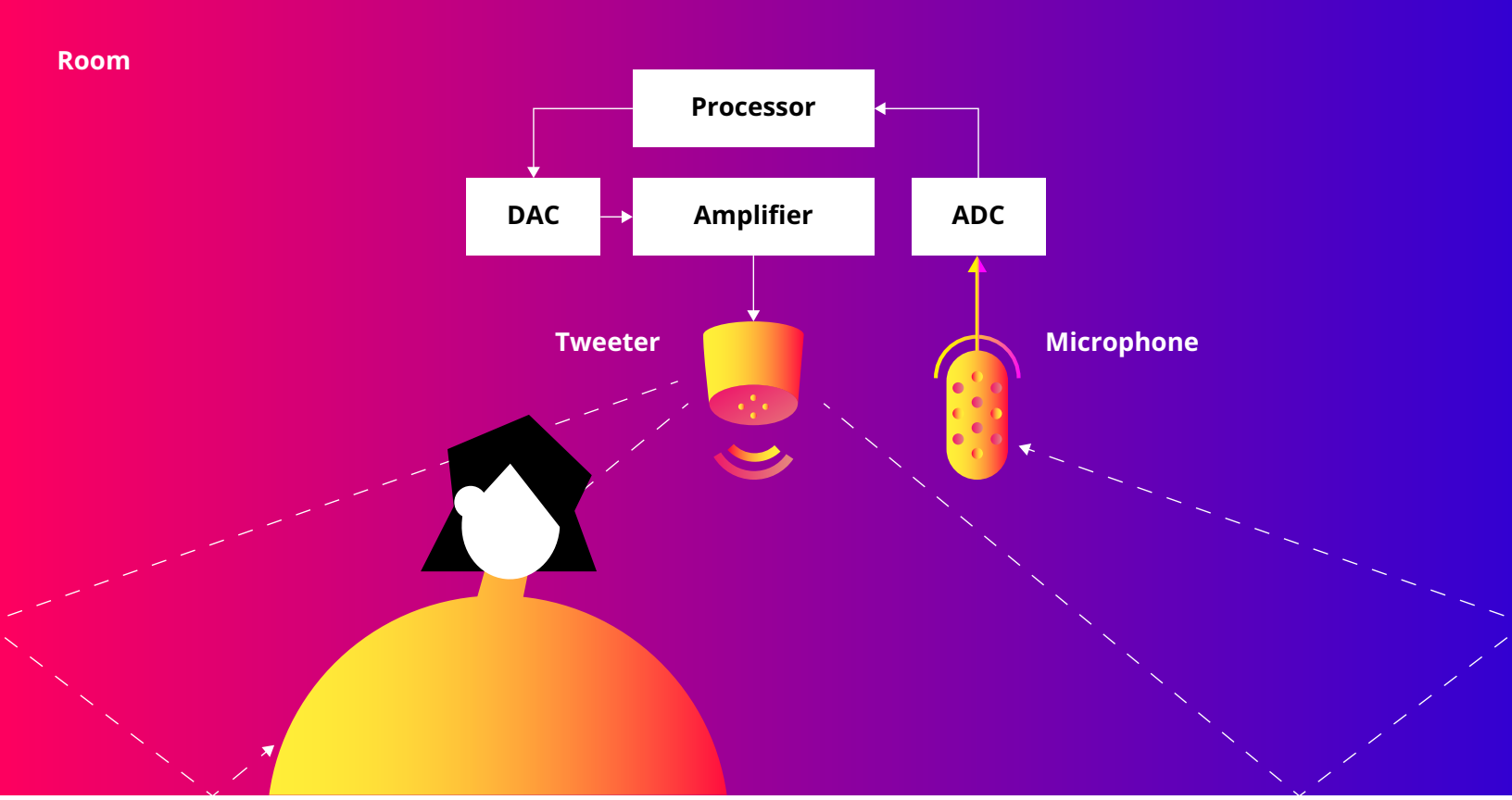


Pros

- Cheapest solution on the market
- Allow detection of movements and direction

Cons

- Should be mounted 120–140 mm from the ground
- Do not count the exact quantity of people simultaneously entering the room
- Error-prone to long distances between transmitter and receiver



ULTRASONIC SENSORS

Ultrasonic sensors use simple radar idea—ultrasonic transmitter generates ultrasonic chirps that are reflected from human bodies. The microphone receives a reflected signal, and, after signal analysis, people are detected and counted. Schematic system design is shown in the picture below, taken from this work that describes the implementation of this system.

Pros

- Silent and safe to humans

Cons

- Not pet friendly
- Accuracy depends on room size. (error estimation results from this work are presented in the table below)
- Require system calibration before usage

	Maximum capacity	*Average error*	*Error/Max Capacity (%)*
Small room	*8*	*0.61*	*7.6*
Medium room	*30*	*1.6*	*5.3*
Large room	*150*	*2.6*	*1.7*

ULTRA-WIDEBAND (UWD) RADARS

UWB radars emit radio waves and analyze the reflected signal. Modern digital signal processing and machine learning techniques are used for signal analysis. They have become very popular because of usage in self-driving cars.

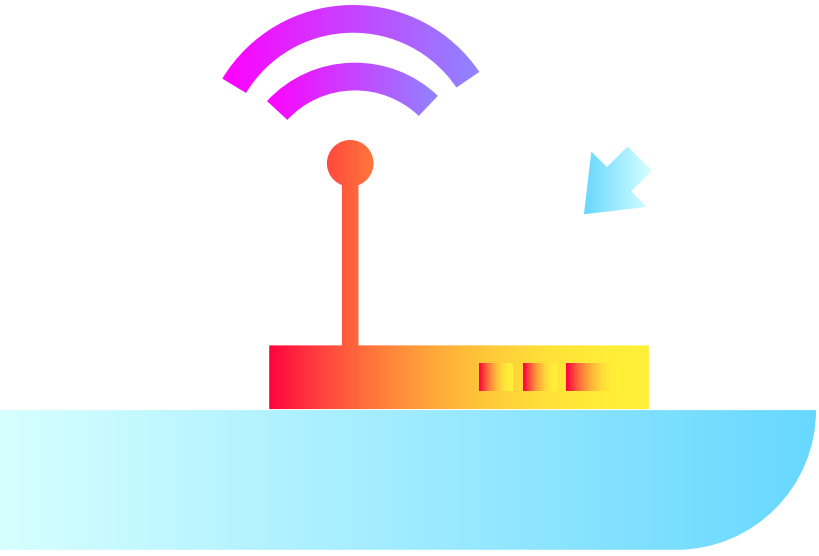
Novelda develops UWB sensors for indoor applications and smart building systems to detect human presence. Let's take sensor based on X4 chip as an example—watch this demo and read this documentation.

Pros

- Cheap, small, and highly technological devices

Cons

- Can interfere with Wi-Fi, Bluetooth, ZigBee, and other customer devices causing interruptions in functions



WI-FI

Technically, Wi-Fi sensing is the implementation of UWB radar technology. The main advantage is that Wi-Fi infrastructure is already present in modern buildings and is used for occupancy detection.

Additionally, Wi-Fi sensing can be utilized in both terminal and non-terminal ways. The radio frequency (RF) signal transmitted by a user's Wi-Fi terminal (smart devices) is analyzed in the first case.

The second implementation does not rely on user terminals but does require the presence of at least two Wi-Fi devices (e.g. a notebook and a Wi-Fi router). One device is used as a signal transmitter, the second—as a receiver.

Early Wi-Fi sensing implementations were based on the received signal strength indicator (RSSI) measurements, whereas more recent iteration use channel state information (CSI) that allows the simultaneous usage of AoA and ToF methods on several signal frequencies. Authors of this work claim that Wi-Fi is already successfully used for detection, recognition, and estimation tasks.

Pros

- Re-usage of existing wireless Internet access infrastructure as an ambient sensor
- Two types of implementation—terminal, non-terminal
- Used for recognition and estimation tasks

Cons

- ML and AI methods used for the measurement analysis require high-performance hardware

MICROPHONE

A microphone captures the noise produced by people in the room. After signal analysis, it is possible to estimate their exact number. Placing an array of directed microphones also allows tracking the position of a noise source. Speech recognition, speech segregation, and noise detection/classification techniques are useful for solving such a task.

Project Ubicoustics is an amazing example of microphone usage. You can learn project details here or watch the video.

Pros

- A lot of devices in the room have microphones already installed

Cons

- Analysis of data from microphones may be considered as eavesdropping

CAPACITANCE SENSORS

Modern painting materials can convert a wall or even an entire room into a capacitance sensor or electromagnetic noise detector that allows detecting people near walls.

Project Wall++ is the best demonstration of possibilities and capacitance of sensors. Find more information here, or watch this video.

Pros

- Almost any room can be converted into a sensor by merely repainting the walls

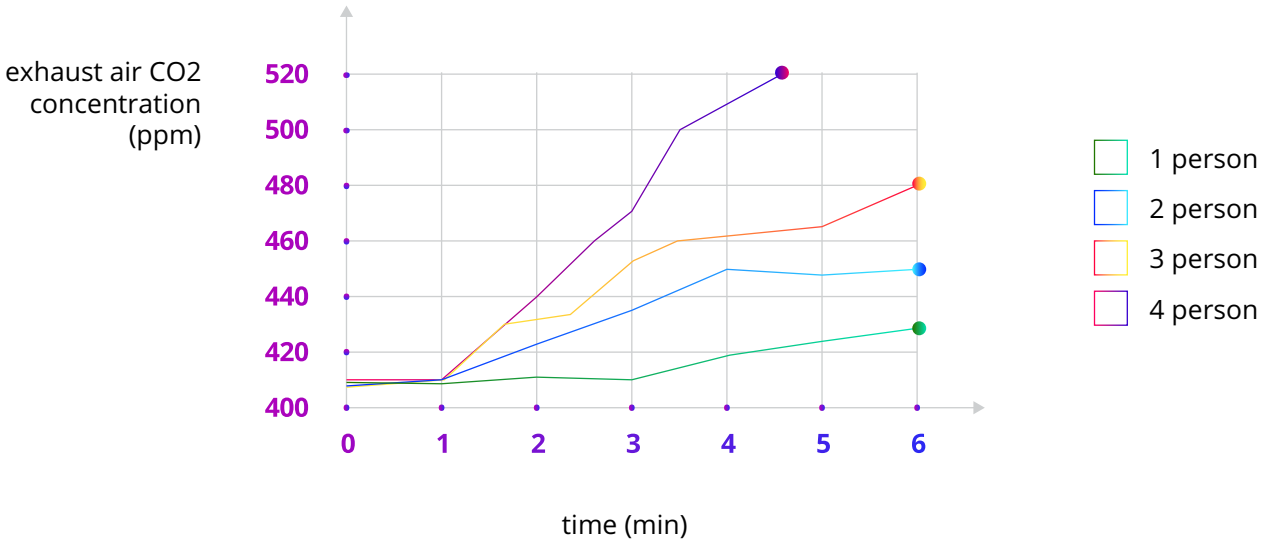
Cons

- The sensitivity is better when people are close to the wall or have some source of electromagnetic noise in a pocket

CO_2 SENSORS

A person releases a certain amount of carbon dioxide while breathing which can be used for occupancy detection. This approach was analyzed in this work, and it was noticed that CO_2 data had to undergo processing to find the most meaningful way to gain valuable information.

In this work, it was shown that it takes some time or CO_2 sensors to predict the exact number of people in the room, and more sophisticated algorithms (controllers) give better estimation results. The figure below taken from this work demonstrates the measured CO_2 concentration in times when a different number of people are present in the room and the ventilation flow rate was set to 3 air changes per hour (ACH).



Pros

- Already embedded in modern air conditioning systems and can be reused

Cons

- Inertial and need some time (about 1-2 mins) to show the correct results

SMART METERS

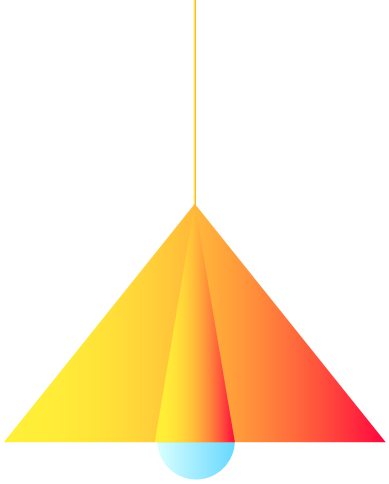
A home's pattern of electricity usage generally changes when occupants are present due to their interaction with electrical loads. An example of such an approach is described here.

Pros

- Existing meter infrastructure can be reused

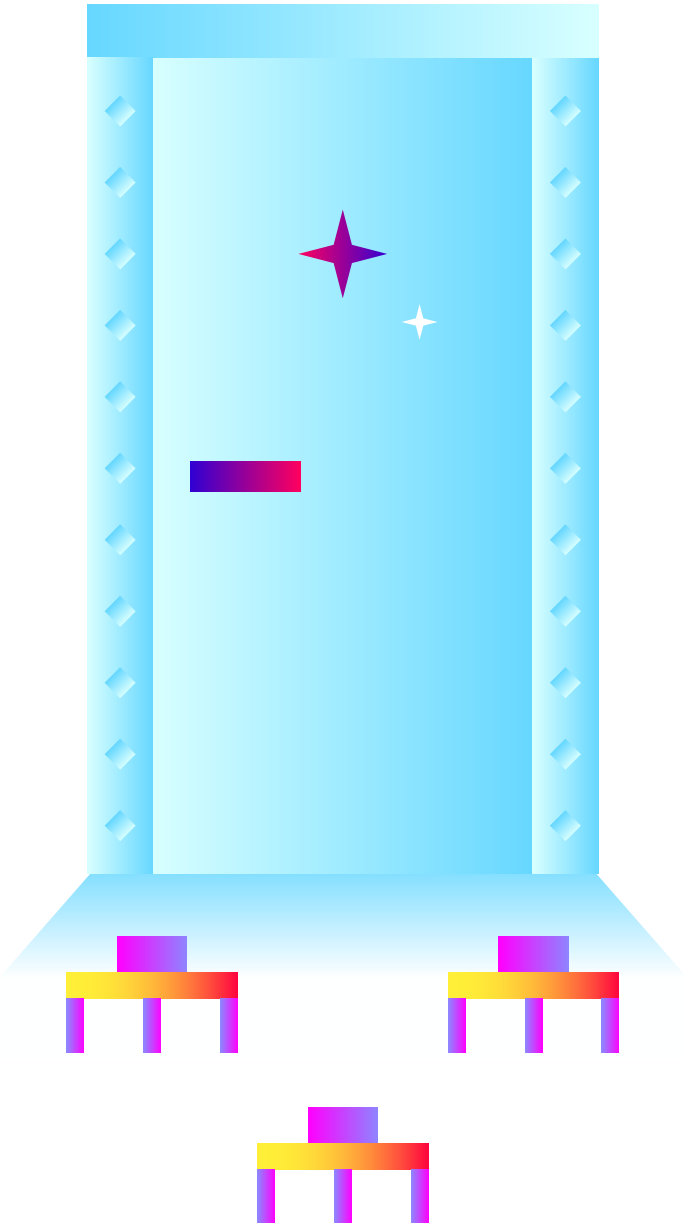
Cons

- Insensitive when people do not use electricity or some other goods



PRESSURE SENSORS

Covering the floor with pressure sensors is also a viable solution for occupancy detection. It is enough to have several sensors near the door for tracking peoples' location across an entire room. The usage of sensor pairs allows detecting movement direction—even paired with break-beam sensors. Descriptions of proposed solutions were found only in works about person identification by tracking walking style.



Pros

- Cheap and reliable
- Improved construction and tested in digital weights scales

Cons

- Require additional changes in floor construction and additional wiring (or wireless solution) to sensor connection

SUMMARY

Overall, there are many approaches available for occupancy detection/people counting. Each of has its advantages and drawbacks—some are useful in certain cases, while quite ineffective in others. An attribute-driven approach can be the most helpful when choosing the most suitable solution. The best way to find the most valuable solution is to weigh in all pros and cons, efforts, and resources needed for its implementation and the needed outcome.

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ABOUT

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Andriy Bench is a SoftServe R&D Engineer providing research in the field of embedded AI and ambient sensing. He also creates prototypes (on Raspberry Pi, Movidius, and Coral platforms), writes research papers and blog posts, and takes part in developing R&D products.

Apart from working at SoftServe, Andriy is a Senior Lecturer at the Theoretical Radio Engineering and Measuring Department of Lviv National Polytechnic University. Here he mentors student teams on robotics and IoT, while also contributing to the ROS Ukraine User Group.

Previously, Andriy served as a Senior QC Engineer specializing in QA, hardware and software reliability, and extensive testing of scripts, mobile, web, automation, and API.

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