Safely Back to Work: How IoT is Enabling Redesign of Spaces in Response to COVID

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INTRODUCTION

The outbreak of the coronavirus pandemic has caused sudden and severe disruptions in the usual ways of working. As COVID-19 spread rapidly, many public places including offices and other co-working spaces were shut down to contain the infection and ensure safety of the employees. Millions of employees had to shift to remote working to ensure the safety of themselves and their families[1]. Prior to the outbreak, offices and workspaces were being redesigned with collaboration and close proximity in mind, with cubicles and rooms torn down to make way for collaborative workplaces. Such spaces however, would now become hubs prone to spreading the virus.

However, as time proceeds and things return back to the “new normal”, workers will need to return to their workplaces. While many workplaces have planned to transition employees back into the offices in phases[1], additional monitoring will be necessary to ensure adherence to the regulatory norms for health and safety such as social distancing, face mask compliance, limit on occupancy, etc. Technology will play a pivotal role in this. In redesigning office spaces, space utilization data of various areas will be crucial. Internet of Things (IoT) and Artificial Intelligence (AI) will play huge roles in data collection, analysis and in the automation of otherwise labor-intensive tasks such as constant monitoring. These technologies can be used to ensure that getting back to work is smooth and most importantly, safe.

MOTIVATION

Effective space management is crucial in any facility/building to ensure proper distancing between the workforce, a key component of a safe workplace in post-COVID times. A prerequisite to this is keeping track of occupancy in different areas within the office over time in order to understand occupancy patterns and redesign the space efficiently[2].

Secondly, forming guidelines and rules around donning facial masks and maintaining a minimum distance from each other while in the facility can do only so much without a mechanism to ensure compliance to these guidelines. A count of people not wearing face masks inside the building can help us quantify compliance to this essential safety requirement, and appropriate measures can thus be taken to ensure compliance. Similarly, monitoring to check social distancing can help us better understand how to redesign spaces. However, it is expensive for businesses to physically

[1] https://www.mckinsey.com/industries/advanced-electronics/our-insights/coronavirus-industrial-iot-in-challenging-times#

[2] https://www.stanleysecuritysolutions.com/people-counting-systems/

monitor and ensure compliance with face masks and/or social distancing. Hence the need for an automated solution.

Sensing technologies and full-stack IoT solutions are now readily available, already having confronted problems such as occupancy detection, indoor location tracking, and employee safety in pre-COVID times. As more sensors are available to track the employees and more devices become connected, the transition back to work can be allowed in a safe and seamless manner. What may not have been possible 15 years ago, is now enabled through the use of efficient and well developed IoT architectures and solutions.

We present a survey and analysis of various cost-effective and easily scalable approaches that can be used to achieve the tasks of occupancy tracking, social distance measurement and facial mask compliance. These approaches make use of either existing infrastructure or minimal additional infrastructural requirements to fulfill these objectives. This is accomplished by the use of various sensors and concepts of IoT, AI and computer vision.

PROBLEM SPACE

Facilities managers at large organizations are faced with many challenges as they are asked to prepare for an employee back to work scenario. In addition, offices are expected to comply with all laws and regulations of the local jurisdiction in redesigning the new office space and workplace experience. The same challenge is faced by many other organizations including but not limited to schools, shopping areas and factories. In order to ensure the safety of employees and workers, the following workplace activities will need to be measured:

Occupancy

Local jurisdictions have begun to enforce restrictions on the number of people that can be accommodated in an indoor location. For example, some restaurants have begun enforcing a 25%-50%[3] capacity or a seating capacity[4]. Office environments have limited the number of employees returning to the office by allowing a certain number of workers back in phases. Occupancy counts will be a very important factor in ensuring that employees are returning back to work in safe numbers. Indoor spaces will vary in the number of employees it will be able to accommodate and will depend on factors like size, window access, air movement, etc. Measurement devices that can accurately determine the number of people in various locations regardless of what type of space it is (office, factory floor, cafe, conference room, etc.) will allow

[3] https://www.cnn.com/interactive/2020/us/states-reopen-coronavirus-trnd/

[4] https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/business-employers/bars-restaurants.html

office management to monitor spaces that are at risk for COVID spread, alert employees when occupancy counts for a space is too high, and collect data for changes in space utilization.

Compliance with Face Masks

Face masks form an effective barrier for the pathogens and prevent infection for other people[5]. Several governments across the world have made the use of face masks in public places compulsory. Offices and workplaces are expected to comply with these orders, but don't currently have a way of monitoring the level of compliance to maintain the health and safety of their workers. Given the vast amounts of spaces where employees will be required to wear a mask, a passive monitoring solution will be effective as a way to measure the percentage of employees wearing masks in the office.

Social Distancing Adherence

In the U.S., the CDC recommends a 6 feet distance between individuals to prevent the spread of COVID[6]. In the workplace, however, employees may be used to congregating together in conference rooms, lunch spaces, and hallways and behavior changes will be difficult to enforce. It is possible that an entire redesign of an office space will be needed to combat this issue, and to do so, an accurate understanding of the movement and idle time of employees will lead to an effective office redesign. Thus, a tool or approach that detects whether individuals are violating the 6 feet separation guidance will allow for insights on what spaces may necessitate warnings, more management, or an entire redesign of the crowded space.

EVALUATION

Our survey details the wide range of technologies and solutions available today that can be applied to this challenging business problem, ensuring that employees are able to return back to work safely and in compliance with the local jurisdiction. This survey will detail the use of video analytics for monitoring occupancy, mask compliance, and social distancing, will go over the use of LiDAR for occupancy counts and social distance measurement, and discuss comparisons between a variety of other sensors.

[5] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html

[6] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html

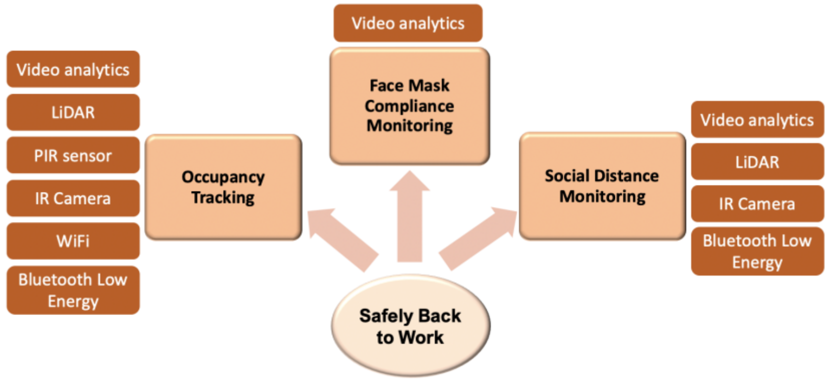

Fig. 1: Problem space and the various available solutions surveyed here

Occupancy

Video Analytics

One way to automate occupancy tracking is by the use of video analytics. It provides the flexibility of reusing the existing surveillance cameras for occupancy analysis. Leveraging existing infrastructure and employing adaptive analytics, we can have automated detection and a real-time count of people in different areas within a facility.

In this approach, cameras installed within the building capture the video feed and relay it to a software running on the computer or on an edge device. The software then processes the video frames to detect people present in it and keeps a count of the same. The count is updated every time the software processes a new video frame captured by the camera. The system can be made real-time with a proper optimized software and good processing capability.

As most of the commercial buildings already have cameras installed for security reasons, the same infrastructure can be used for occupancy tracking in this approach, thus reducing the infrastructural cost for implementing this solution. Moreover, with minimal infrastructural changes required, this approach is very easy to implement for occupancy tracking.

However, care should be taken to comply with laws around surveillance per the jurisdictions where this technology is deployed. The definitions of a workplace or a public place where such technology is deployed could differ. Same with labor laws in various states and around employer-employee relationships. For example, a business in Illinois that could potentially collect the biometric information of the employees should ensure it follows the appropriate processes with respect to (740 ILCS 14/) Biometric Information Privacy Act[7].

While security camera infrastructure could be utilized for occupancy tracking, many areas in offices/workplaces are not usually tracked by security cameras and this would require addition

[7] https://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=3004&ChapterID=57

of more hardware. For example, security cameras typically track the entry/exit areas but not the office occupancy areas.

Video analytics is also limited by the ambient lighting and the field of vision of the cameras.

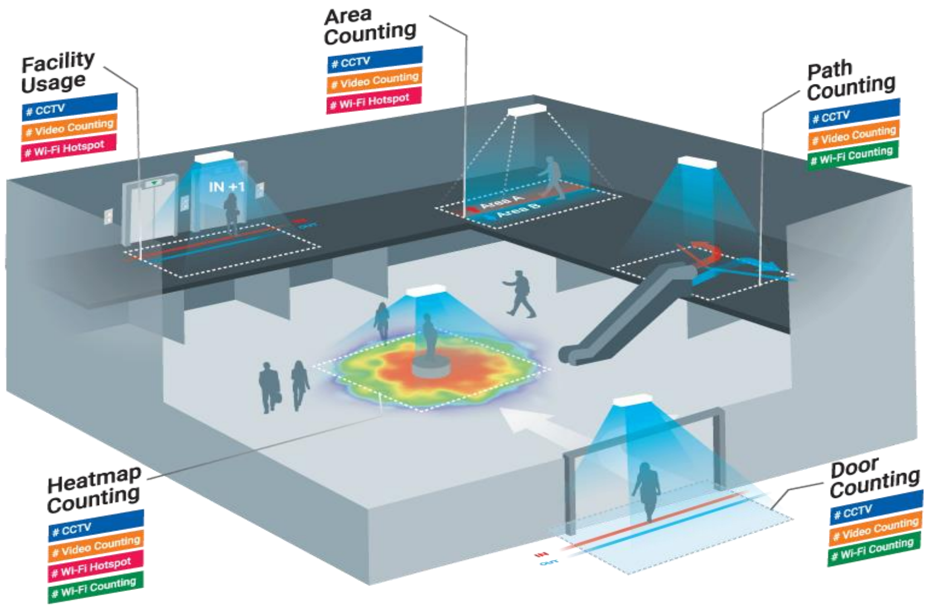

Fig. 2: Tracking occupancy using video analytics (From footfallcam.com)[8]

LiDAR

Light Detection and Ranging (LiDAR) sensors use near visible light spectrum to image objects. LiDAR sends a light pulse and based on the time it takes for the pulse to travel back after reflection, determines the distance to that point in the given space. By combining light pulses of varying wavelengths to scan and measure the area around them, the LiDARs create a high-resolution image of their surroundings, also called a 3D point cloud. While popular in automotive applications, this same feature of LiDAR makes it a good fit for monitoring and tracking applications for office space occupancy.

[8] https://www.footfallcam.com/Industries/SmartBuildings

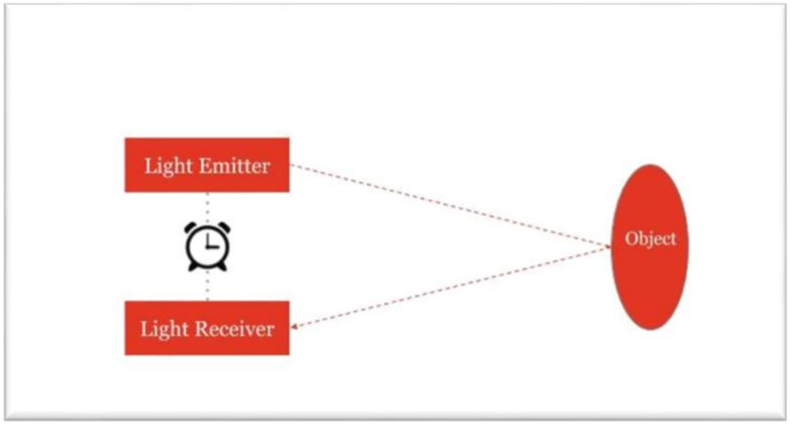

Fig. 3: LiDAR basic principle

While the usage in tracking occupancy is relatively new, one advantage of LiDAR based occupancy tracking is that it will help monitor the space without capturing the identity of the person being tracked. This could be a huge advantage in applications where privacy of the individual being tracked is of concern. The range of the LiDARs varies from a few feet to up to 200 feet. They are typically mounted on the ceiling or set up on a shelf high enough to get the desired range.

Another defining feature of LiDARs is the ability to resolve between objects that are very close to each other as compared to other sensing technologies. LiDARs work indoors and outdoors, in varying degrees of lighting and darkness, and are very reliable in reporting of occupancy. However, the range is limited by any obstructions in its path. LiDARs cannot detect objects behind walls or columns.

LiDARs are considered to be generally expensive compared to other technologies, and indeed they are when we look at it on a per LiDAR basis. But when looked at from a per square foot perspective, as it is done in commercial real estate, the price is quite competitive compared to other technologies.[9] This is due to the fact that the LiDARs offer a range of visibility that is not matched by other sensing technologies.

Recent developments in miniaturization, power efficiency and a move towards solid state electronics (as opposed to mechanically rotating parts) are contributing to a more price efficient set of LiDARs. Early deployments have been in areas where the coverage can be maximized, e.g., airports, conference centers, libraries etc.

The general principle of operation of LiDARs for occupancy tracking is as follows: scanning to create a point cloud of the environment around the LiDAR. Then these point clouds are enhanced

[9] The price of LiDAR was calculated using examples of some LiDARs on the market and the range they cover in square feet. The same calculation was performed for installation of other technologies including cameras and PIR sensors whose per device price is lower than a LiDAR (in general) but the range they cover is a lot lower as well.

by multiple scans and these data points are stitched together in software that runs either on the LiDAR itself or on a computer attached to it. A set of baseline scans are performed to get a sense of the environment, i.e., the set of stationary objects as seen by the LiDAR. After that, any moving object can be detected against that background and assigned a unique ID. Thresholds can be set to only monitor moving objects that meet a certain height or width requirement in order to track people as opposed to cars or carts. This is how LiDAR tracks occupancy. Multiple LiDARs can be set up in overlapping zones, all connected to a single software management system in such a way that each moving object can be tracked seamlessly across many LiDARs.

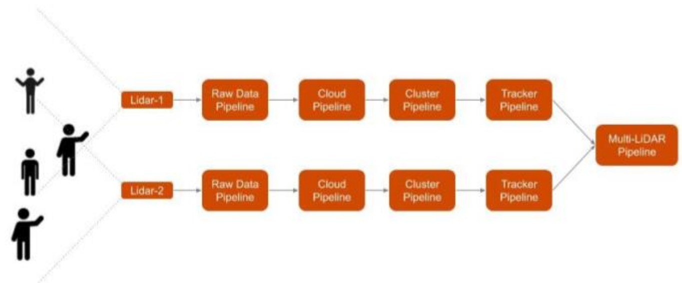

Fig. 4: Multi LiDAR based Occupancy tracking system

PiR Sensors

All objects, whether animate or inanimate, emit heat energy in the form of radiation of wavelengths in the infrared range (~700 nm to 1 mm). This radiation is invisible to the human eye, but can be detected by various devices. A PIR sensor works on this principle. These sensors consist of pyroelectric materials that generate a voltage when exposed to heat. Objects which differ in temperature and surface characteristics emit different amounts of radiation, and can hence be differentiated by the PIR sensor.

These sensors are widely used for motion detection. As a person passes through the sensor's field of view, the sensor "sees" it as a differential in temperature against the background. The sensor converts this change in the IR radiation into a change in output voltage, which is detected[10].

[10] https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor

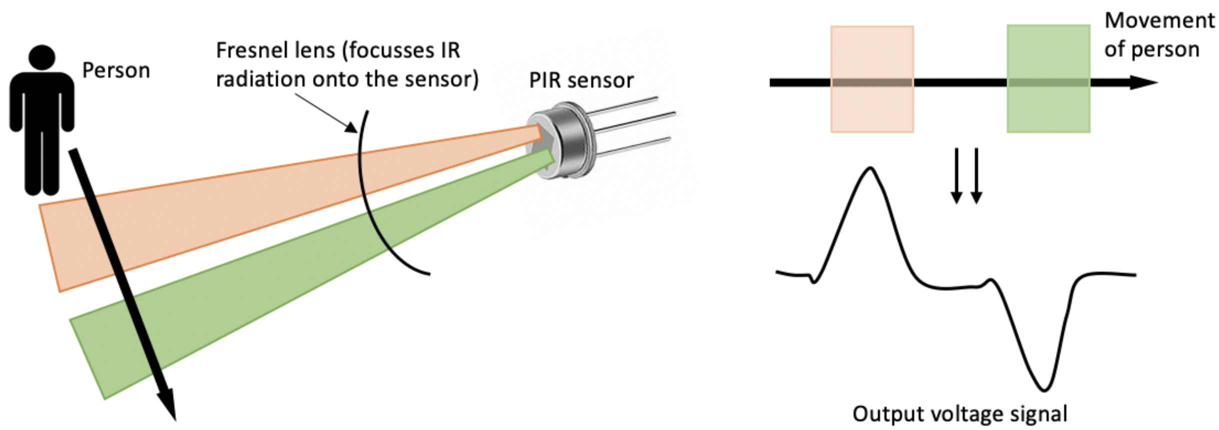

Fig. 5: Working of a PIR sensor

PIR sensors are popularly used for indoor occupancy detection due to their low cost, low energy consumption, large detection range, and wide field of view. They are commonly deployed with lighting systems to turn off lights in offices, conference rooms etc. when they do not detect movement for a defined period of time. However, while great at detecting motion, PIR sensors can only provide occupancy status in a binary status: occupied or not. They cannot tell how many people are in a certain area (e.g., conference room) in any reliable fashion.

IR Cameras

An InfraRed Camera is a camera that detects infrared energy (instead of visible light, as in a regular camera) and turns that into a color-coded image of observed temperature gradients. An IR camera is equipped with a sensor chip that consists of a grid of small detectors. Each detector is able to detect the infrared energy, producing a signal that is then converted to a color that corresponds to the temperature. This color map is the resulting output of the camera viewing a specific area or environment[11].

[11] https://www.fluke.com/en-us/learn/best-practices/measurement-basics/thermography

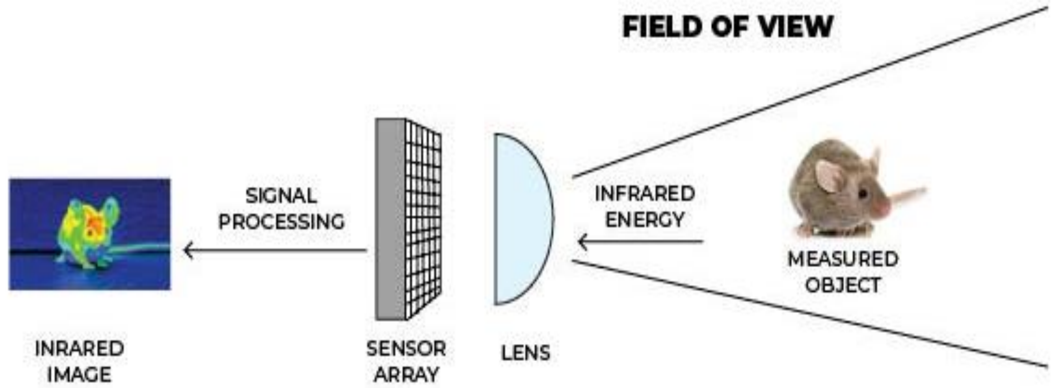

Fig. 6: Field view of a PIR Sensor

This is useful for occupancy detection, because each individual in an environment will emit light in the infrared region at a higher level than other objects in the space. By separating these individuals with higher light emissions from the area being inspected, the output of the camera will be an image with various "blobs" representing each individual person. The "blobs" can thus be counted and the number of occupants in space can be measured[12].

Infrared cameras have the added benefit of being able to anonymously detect the presence of individuals without being dependent on the movement of those individuals. However, challenges occur when individuals are very close to each other and appear as one "blob" leading to inaccurate counts.

WiFi

The majority of the large commercial/institutional buildings have WiFi networks. Most of the laptops and smartphones within the building are connected to this wireless network via different access points. This technology can detect both occupants' presence and count within the premises and hence can be used to form an occupancy tracking system.

Whenever a person enters the premises with a WiFi-enabled device, such as a laptop or a smartphone, the device scans for the WiFi access points (AP) present in the vicinity. Each access point whose range coverage the device is in receives the identification of the device and the strength of the signal that the device is receiving from that particular AP. The former is the MAC (Media Access Control) address[12] of the device. The latter is called the RSSI (Received Signal Strength Indicator)[13] of the device. Using this data received by the various APs in the vicinity of

[12] https://www.researchgate.net/publication/224195975_Room_occupancy_measurement_using_low-resolution_infrared_cameras

[13] https://www.mncee.org/MNCEE/media/PDFs/Wi-Fi-LBS-Tech-Overview.pdf

the device, the distance of the device from each AP can be estimated. Using these individual distances from each AP, the location of the device and that of the person carrying it can be approximated by the method of trilateration[14,15]. This location data can be used for tracking occupancy of various areas within the premises.

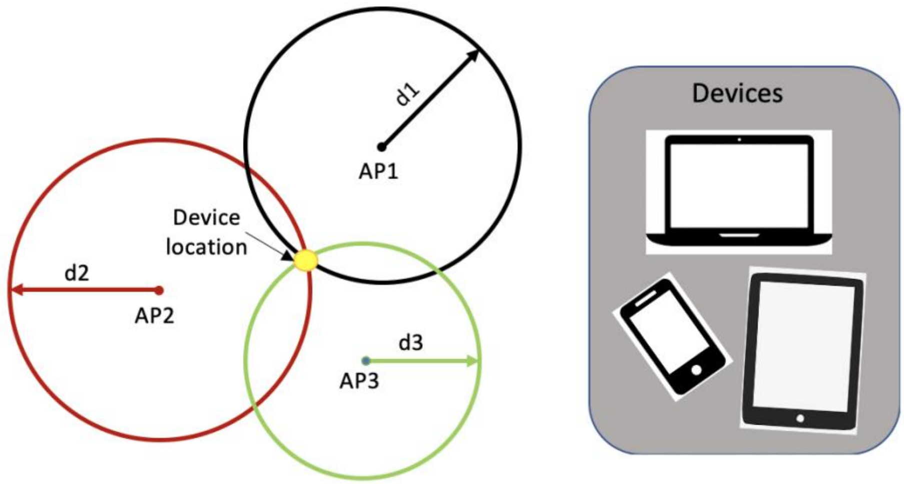

Fig. 7: Device location approximation using trilateration method (AP stands for access point; d1, d2, d3 are approximated distances of the device from AP1, AP2 and AP3 respectively)

This approach for tracking occupancy is becoming popular because most of the buildings will already have WiFi networks set up, hence there is no need for any infrastructural addition or changes for using this technology. This method of measuring occupancy assumes that many people who visit the facility will carry at least one active WiFi-enabled device for their communication needs. Moreover, no additional hardware (such as BLE tags or RFID tags) is required for tracking occupancy in this approach. However, this method provides an inaccurate count of people in case people are carrying more than one WiFi-enabled device with them.

Bluetooth

Bluetooth Low Energy (BLE)[16] is a wireless technology designed for fast periodic transmission of small amounts of data over short-range distances at much lower power consumption and lower cost as compared to classic Bluetooth. As it is mainly used to transmit small amounts of data periodically, it does not require a continuous connection, thus reducing the power consumption.

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[14] https://en.wikipedia.org/wiki/Wi-Fi_positioning_system

[15] https://www.ijser.org/researchpaper/Wi-Fi-Indoor-Positioning-System-Based-on-RSSI-Measurements.pdf

[16] https://elainnovation.com/what-is-ble.html

BLE beacons are battery-powered transmitters that transmit a small amount of data over a short distance at periodic intervals of time. These beacons are attached at known locations around the facility. The smartphones carried by employees/staff act as BLE receivers combined with an app that constantly scans for nearby beacons. The detected beacons and associated radio signal levels are reported by the phone app to a backend cloud software. The cloud software then processes this information received from the phone apps to track the location (and hence occupancy) within the facility. Conversely, in some other implementations, the roles could be reversed where the BLE beacons (or tags) are issued to staff and the BLE readers are set up throughout the facility to track the location of the assets/people who are carrying the respective BLE tags[15]. The latter method does not depend on the staff having an appropriate phone and the BLE management app.

BLE technology is widely used for real-time location tracking as well as occupancy tracking within premises. It is very popular because of its low cost, very low power consumption leading to long battery life and easy installation and integration with existing infrastructure and systems.

COMPLIANCE WITH FACE MASKS

Video Analytics

In office spaces, cameras are usually installed in common areas, hallways, etc. for security surveillance reasons. These cameras capture faces of people in their field of view. This feed can be relayed to a software running on a computer. This software consisting of deep learning models trained to detect human faces and classify them as masked or unmasked can process the frames and keep a count of people without facial masks.

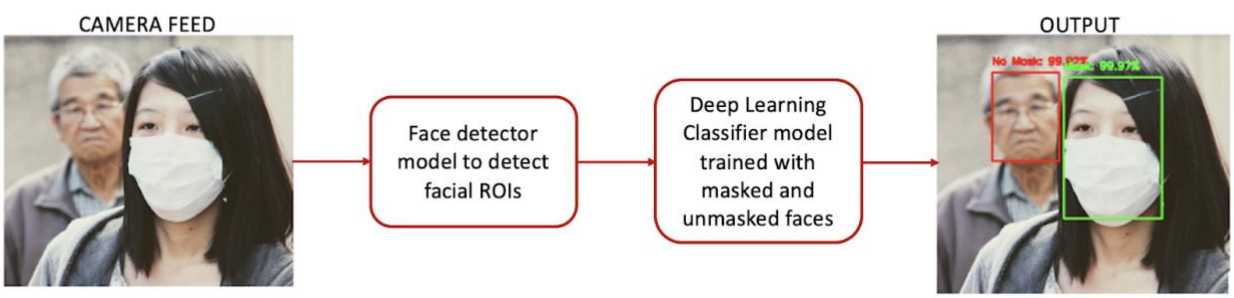

Fig. 8: Automated monitoring of face mask compliance

This approach provides the flexibility of reusing the existing surveillance cameras for monitoring and measuring facial mask compliance, thus ensuring minimal infrastructural changes and cost-effectiveness. However, the proper positioning of cameras[17] is crucial to ensure accurate results

[17] https://surveillancereviews.net/best-security-camera-placement-home-office/

with this approach because the mask-detection software gives correct results only when the detected face is almost frontal.

Social Distancing Adherence

Video Analytics

Video surveillance can be an effective way to monitor public places for violations of social-distancing guidance. A video camera is mounted at height that can capture the maximum area that can be monitored without diminishing the quality of image. The video feed is then passed on to a computer software that detects people in a video frame and analyzes their positions to estimate if two people are close to each other. The optimum height, position and angle of the camera needs to be determined for the space being monitored[18].

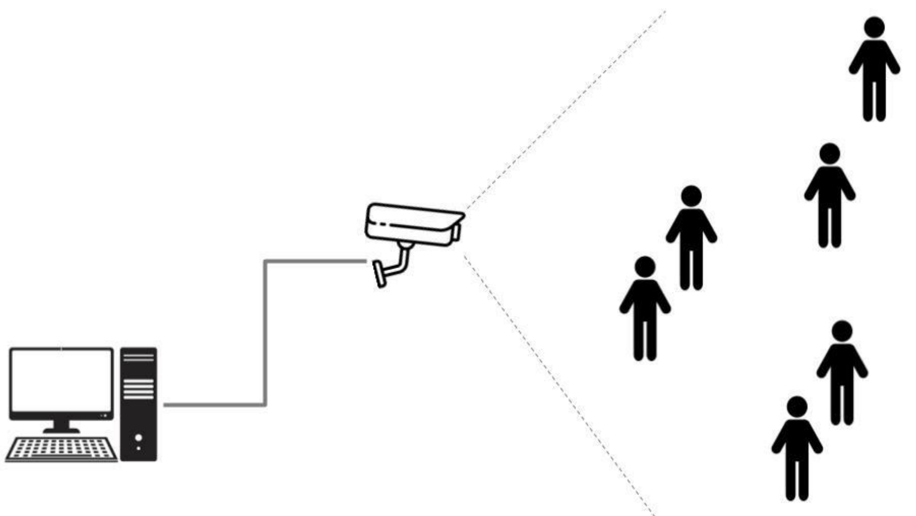

Fig. 9: Social Distance Monitoring via Video Surveillance

[18] https://www.farsight.co.uk/blog/where-to-position-cctv-cameras-in-your-business/

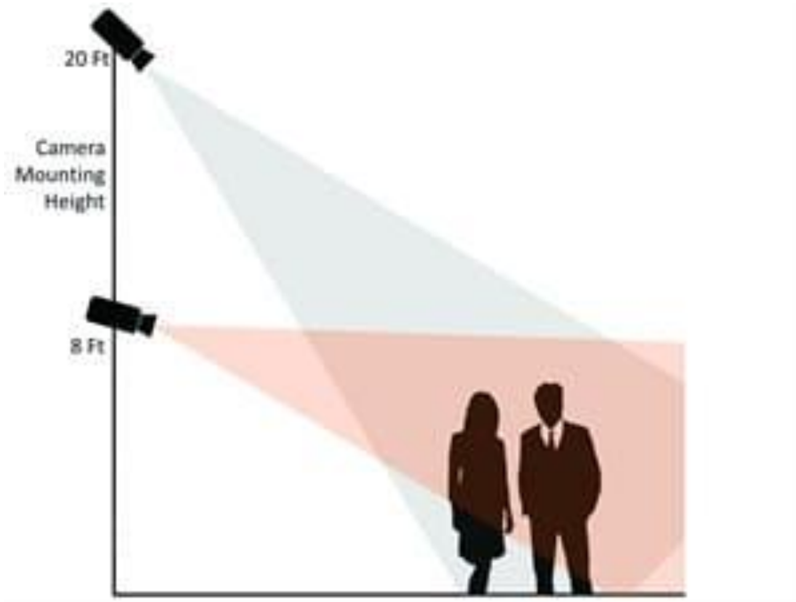

Fig. 10: Positioning the camera (from surveillancereviews.net)[16]

One approach is that the software running on the computer can use two Deep Learning models[19] (Multi-layer Neural Network) that provide intelligence to the system. People in the frame are detected and localized using an object detection[20] model, while a depth estimation[21] model tries to predict the distance of detected people with respect to the position of the camera. This data is passed on to a custom algorithm to conclude if people in the given video frame are following the social-distancing guidance.

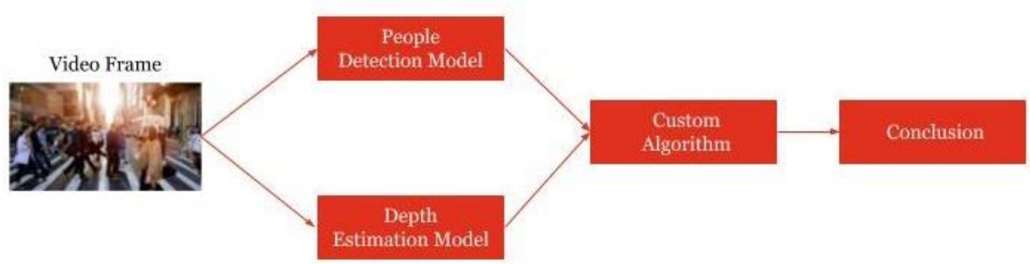

Fig. 11: Process flow for Social Distance Monitoring via Video Surveillance

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[19] https://en.wikipedia.org/wiki/Deep_learning

[20] https://machinelearningmastery.com/object-recognition-with-deep-learning/

[21] https://towardsdatascience.com/depth-estimation-1-basics-and-intuition-86f2c9538 cd1

Edge devices having capability of processing Deep Learning models can be used for on premise processing of the data. Edge here refers to the computations that will be performed locally on the device itself. The camera can be directly connected to the compute device which can capture and infer frames in near real-time. An ideal device for this kind of processing would have an on-board GPU for low latency inference and good memory for local computations.

LiDAR

The LiDAR is placed on the ceiling or on a wall so as to capture a wide area and angle. Similar to how LiDAR would be used to calculate occupancy, moving objects will be assigned a unique ID and with a multi-LiDAR set up, the data of the moving object will be aggregated and tracked across multiple LiDAR zones, appearing on the LiDAR software platform as one object. Each object will have normalized x, y, z coordinates across all zones to indicate a specific position at a given timestamp. The LiDAR software platform can perform simple math operations to compute distance between objects. By measuring this distance and setting thresholds so that it only records moving objects that are people, one can measure that the distance between individuals are at least 6 feet in order to ensure compliance with social distancing guidance.

IMPLEMENTATION CONSIDERATIONS

Video Analytics for Occupancy Detection

Implementation of video analytics methodology for tracking occupancy requires proper placement of the camera so that its field of view is maximised. The camera needs to be mounted at a height of about 6-7 feet above the ground so as to get a wide field of view. At the same time, it needs to be ensured that people's faces are clearly visible in the feed captured by the camera so that occupancy can be tracked accurately. The camera resolution, lighting condition in the area and camera position all play a significant role in this. Moreover, if there is more than one camera installed in one closed space such as a room, the overlap in their fields of view has to be accounted for to get an accurate count of occupancy.

Video processing is a processor-heavy task, and hence a good amount of processing capability will be required to implement this method locally for real-time occupancy tracking. A workaround for this is the use of cloud services for processing, but this is bandwidth heavy and also gives rise to some concerns related to privacy of data and/or have compliance issues with privacy regulations depending on where the data is being stored.

Video Analytics for Social Distancing

As video analytics relies on camera feeds which in turn relies on other factors such as lighting condition, pixel quality of image, position of camera, overlapping objects, etc. this solution does have some limitations.

Glass or polished surfaces show the reflection of the actual object present in the scene which may be indistinguishable by the computer software. While calculating the depth of the object in an image with reflective surface, the model may estimate wrong depth which can lead to miscalculation in social distancing.

Fig. 12: Reflection of image in The Bean at Chicago

The deep learning model running beneath the computer software is trained to detect and classify humans in a given image. The training images consist of 2D image representations of the 3D world; hence it is hard for such models to differentiate between a mannequin and actual humans. In some cases, it may happen that a person is standing next to a mannequin and the system mis-classifies it as a social distance violation.

Fig. 13: A mannequin being detected as a person standing at ~16 meters from camera

If a person is standing in front of another person in frame then it may happen that one would obscure the view of another person. Hence, only one person will be detected by the system as the camera could not capture both of them.

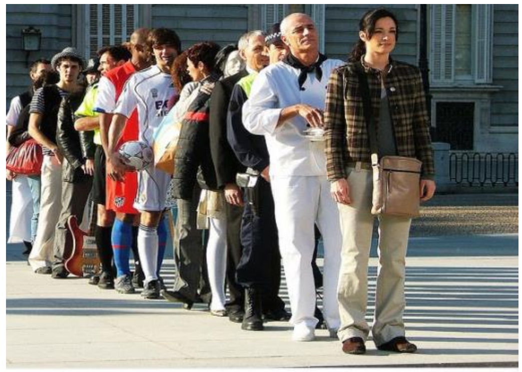

Fig. 14: People obscuring the view of those standing behind them

People wearing clothes of color similar to the background may be imperceptible by such a system.

Fig. 15: People wearing clothes matching with the color of wall

Video Analytics for Mask Detection

For using the video analytics method for monitoring facial mask compliance within premises, it's very important that cameras are placed in a way so as to capture almost-frontal faces of people. Most of the algorithms for mask detection work well only up to a certain angle of the face with respect to the camera. A good way to ensure proper facial orientation would be to place cameras directly opposite to doorways so that people face the camera while entering into the room. Along with proper placement, performance of the system will also depend on ambient lighting conditions, camera resolution, etc.

Mask detection algorithms are mostly deep learning models, whose performance depends highly on the examples that the model is trained on. For an accurate classification, it's crucial to train the model on a good number of both masked and unmasked human faces. It is also important to have a balanced dataset, i.e., an almost equal number of training examples from both the classes, so that the model's performance is not biased towards any particular class[22].

As an example, we trained a MobileNetV2 classifier[23] on 750 images each of masked and unmasked human faces, with an 80%-20% split between training and testing images[24]. With this model, we were able to achieve a validation accuracy of ~97% and F1 score >0.97 for both the classes. Another major aspect is the speed of inference of the model as an ideal monitoring application needs to be real-time. For good speed, it needs to be ensured that the model is light-weight, i.e., computationally less expensive. One way to achieve this is by using convolutional neural network architectures that use depth-wise separable convolution rather than simple convolution[25]. This would reduce the computation load and increase the speed of inference of the system.

LiDAR

While a great technology with a good range and resolution between objects, LiDAR requires detailed planning, as an entire view of the space is necessary for more granular tracking. Therefore, it is recommended to mount LiDAR systems at least 5-6 feet above the ground in order to get a 360-degree view of the space and be fully visible within the space[26]. Like most light spectrum-based tracking systems, LiDAR is not able to penetrate walls and requires a non-obstructed view of the objects that need to be tracked. For this reason, LiDAR systems should be placed in every enclosed room or above smaller separated areas such as cubicles or desks. Though LiDAR systems can scan up to a maximum range of 200 meters; the accuracy in tracking people is best at a range of 50 meters[27]. Given that LiDAR can work in various types of weather, use cases can be expanded to outdoor solutions that may need to track the number of people in a public space, and/or a parking lot. This is especially useful for social distancing use cases where social distancing is necessary in both indoor and outdoor spaces.

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[22] https://machinelearningmastery.com/what-is-imbalanced-classification/

[23] https://towardsdatascience.com/review-mobilenetv2-light-weight-model-image-classification-8febb490e61c

[24] https://machinelearningmastery.com/train-test-split-for-evaluating-machine-learning-algorithms/

[25] https://www.geeksforgeeks.org/depth-wise-separable-convolutional-neural-networks/

[26] http://teecom.com/media/TEECOM-Occupancy-Measurement-Analysis-Report.pdf

[27] https://www.konicaminolta.com/us-en/future/3dlr/index.html

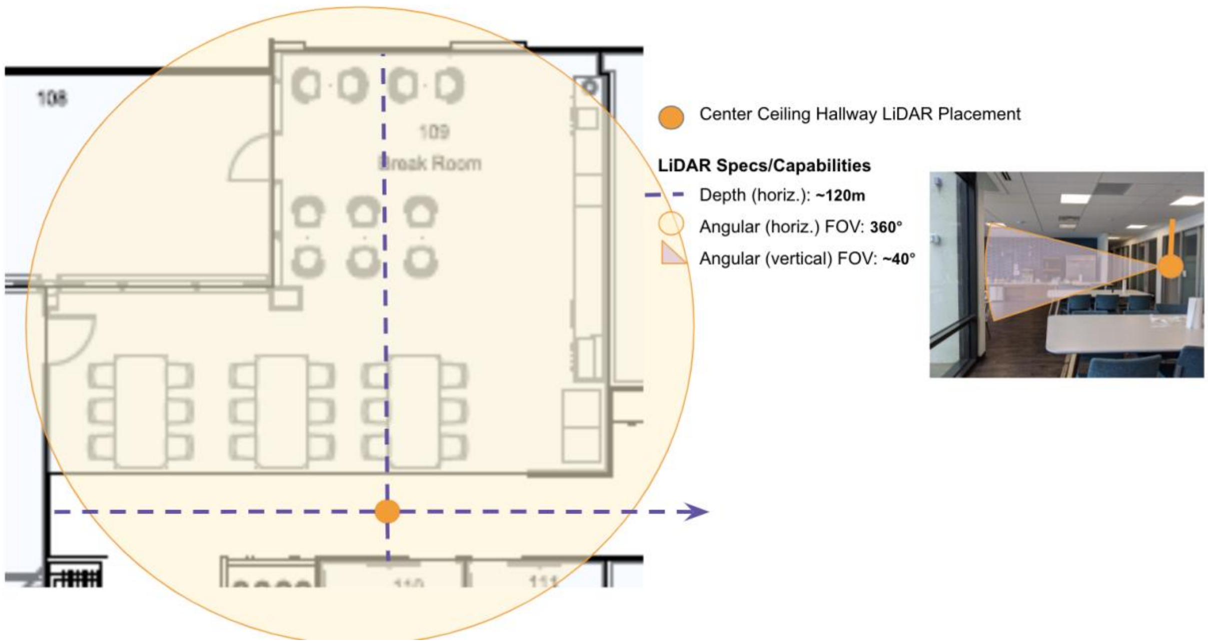

Fig. 16: Area covered by LiDAR sensors

Given the amount of data collected by the LiDARs during the scans, the bandwidth generated by each LiDAR would require a separate wired connection so as to not interfere with operation of other wireless systems in the space. In a multi-LiDAR system, a separate network is created to carry the scan information from the LiDARs to the software processing system for calculation and presentation.

CONCLUSION

The presented sensing technologies showcase the various approaches one could take in designing an IoT-enabled solution that allows for employees to return safely back to work. We have detailed the benefits and tradeoffs of each technology, showing that the chosen approach depends on the use case and requirements of the space and business.

	Use Case	Advantages	Disadvantages	Complexity of Implementation	Cost	Range
Video Analytics	Occupancy tracking; Face mask detection;	Near Real-time	Light dependent; Privacy issues; Requires high processing	High	Medium	Depends on camera resolution, focal length,

	Social Distancing		power; Requires high system memory			lighting conditions
LiDAR	Occupancy Tracking; Social Distancing	Privacy is preserved; Near Real-time	Requires high processing power	High	High	Up to 100 meters
PiR Sensors	Occupancy Tracking	Privacy is preserved	Does not detect stationary people; Cannot distinguish number of people	Low	Low	Up to 10 meters
Infrared Cameras	Occupancy Tracking; Social Distancing	Privacy is Preserved; Near Real-time	Accuracy declines if individuals are close together	Medium	Medium	Depends on camera resolution, focal length, lighting conditions
WiFi	Occupancy Tracking	Can be integrated with existing system	Gives wrong measure of occupancy if a person is carrying >1 device or no devices connected to	Medium	Low	Up to 50 meters

			the WiFi network			
Bluetooth	Occupancy Tracking; Social Distancing		Limited battery life	Medium	Low-Medium	Up to 20 meters

Table: Summary of Safely Back to Work survey

A sensor that gives high accuracy may not be able to provide the cost savings a business needs. Alternatively, a sensor that gives near real-time analysis may not be battery efficient. Additionally, implementing these technologies will require thorough planning and design. Information on where these sensors need to be placed to capture accurate information on movement of individuals in the space as well as how these sensors might fail are important considerations. As businesses aim to maintain the health and safety of their workers, Internet of Things technologies are the enablers for the necessary monitoring and tracking that can ensure worker safety.

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