COVID-19 Safe Distancing Measures in Public Spaces with Edge AI

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Government Technology Agency of Singapore (GovTech)

- Is a statutory board of the Government of Singapore, under the Prime Minister's Office
- **5 Capability Centres**, conducting **3 key activities**

ENGINEERING EXPERTISE in:

- Sensors & IoT (SIoT)
- Cybersecurity
- Data Science & AI
- Infrastructure
- Applications Design, Development, Deployment

TECHNOLOGY EXPERIMENTATION

- Generate key technologies for Whole of Government
- Establish key partnerships with industry players and research institutions

PRODUCT ENGINEERING & DEVELOPMENT

- Develop core technologies, standards and guidelines

TECHNOLOGY ADVISORY & CONSULTANCY

- Provide technical consultation.
- Develop POCs and products

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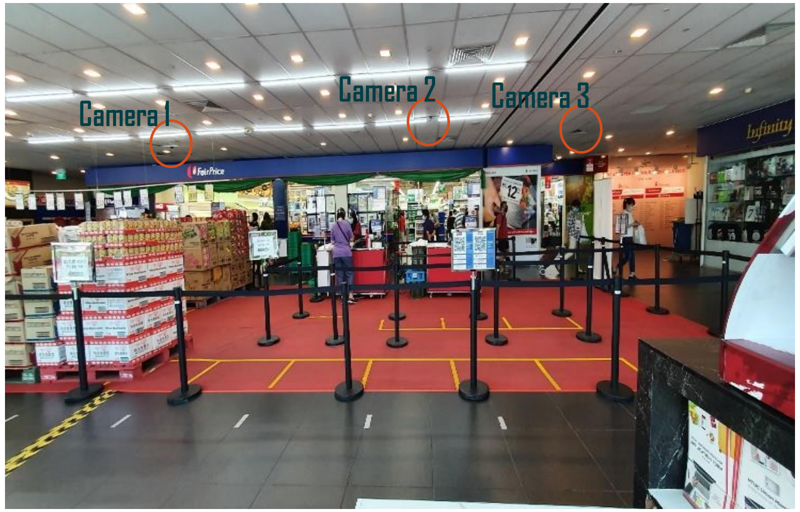
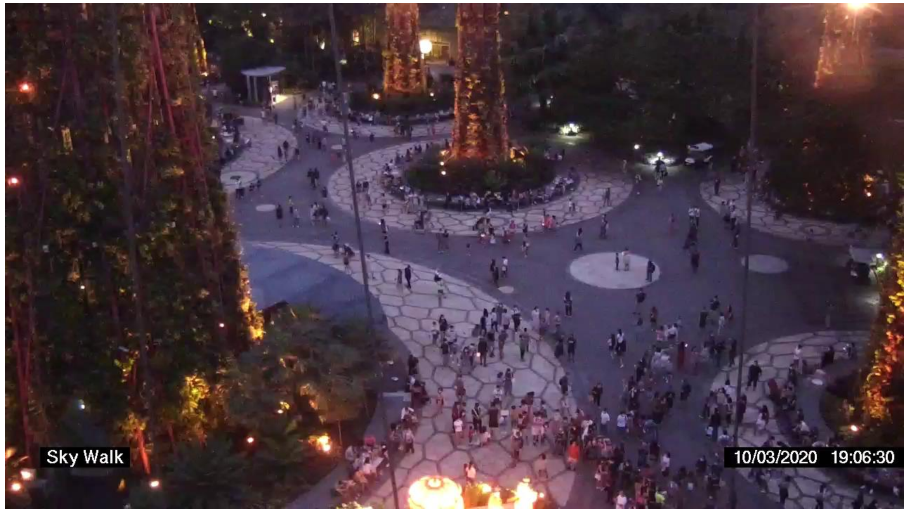
Introduction

- Whether it's indoor environments (supermarkets, museums, etc.) or outdoors (parks), **crowd management** is a priority.
- By combining **edge AI** solutions with **cloud** connectivity, government agencies are equipped with information they need to **manage the crowd** effectively.
- Crowd counting deployments on the edge in **indoor** & **outdoor** environments are presented.



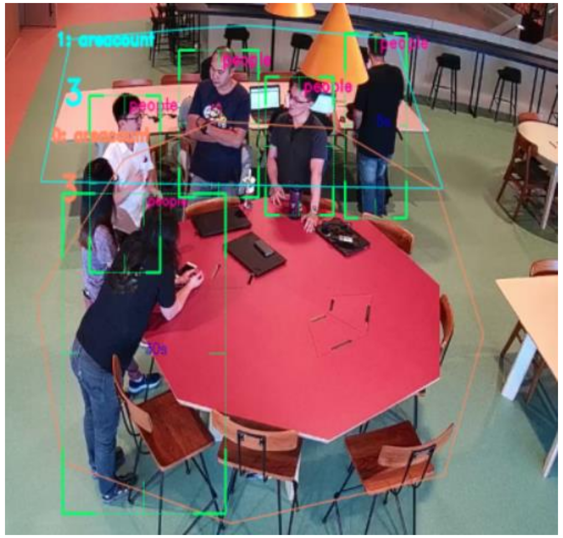
Indoors – Supermarkets, offices, museums



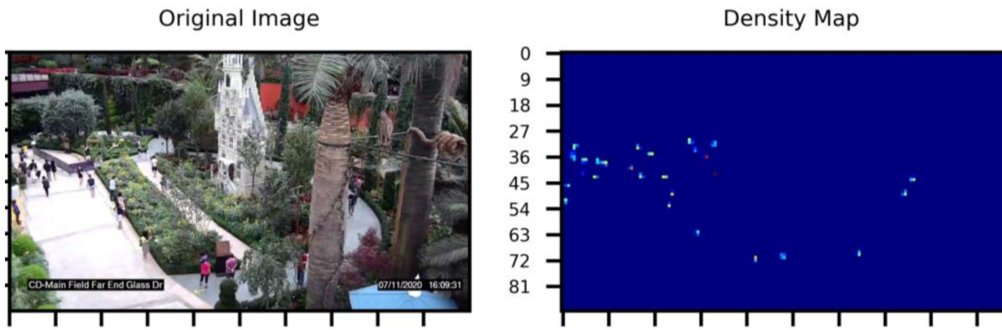
Outdoors - Parks

Key Approach in Indoor & Outdoor Visitor Counts

- Current state-of-the-art methods treat crowd counting as:
  - Detection-and-counting approach
  - Density map estimation
    - Where a deep neural network first produces a 2D crowd density map for a given input image, and…
    - …estimates total size of the crowd by summing the density values across all spatial locations of the density map.



- For large crowds, the density map estimation approach is more robust than the detection-then-counting approach
  - as it is less sensitive to occlusion and clutter.
  - does not need to commit to binarized decisions at an early stage.



People Counting in Indoor Environments - Hardware

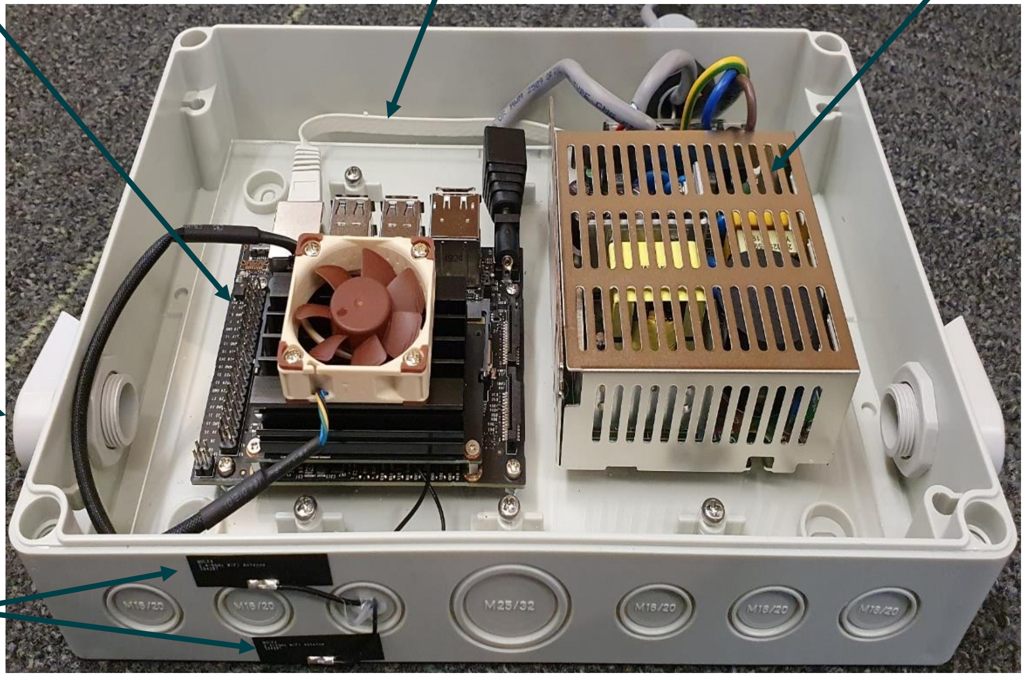
Nvidia Jetson Nano

Camera Data Cable

AC-DC Power supply

Vent

Wi-Fi Antenna



Nvidia Jetson Nano Dev Kit

Aaeon BOXER-8223AI NVIDIA Jetson Nano

One edge device can process up to 2 cameras.

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People Counting in Indoor Environments - Software

	Version 1	Version 2
Model	SSD-Mobilenet v2	PeopleNet
Pre-trained dataset	MS-COCO	Nvidia Proprietary
Initial Object Classes	80	3
Object class after transfer learning	1 (i.e. person)	1 (i.e. person)
Model optimization	TensorRT (FP16)	TensorRT (FP16)
DeepStream	No	Yes
Tracking	Simple Online and Realtime Tracking (SORT) https://github.com/abewley/sort	NvDCF tracker
Accuracy	86%	91%

Software Version	Model	TensorRT	FPS	CPU Usage	GPU Usage	RAM Usage (Gb)
Version 1	SSD Mobilenet v2	No	17	49% (avg.)	70% (avg.)	2.9 / 4.0
	SSD Mobilenet v2	Yes	23	35% (avg.)	50% (avg.)	2.7 / 4.0
Version 2	Nvidia PeopleNet	Yes	25	40% (avg.)	50% (avg.)	2.7 / 4.0

People Counting Indoors

- Transfer learning with custom dataset can achieve detection accuracy > 91%.
- (Almost) a solved problem!

Crowd Counting in Outdoor Environments

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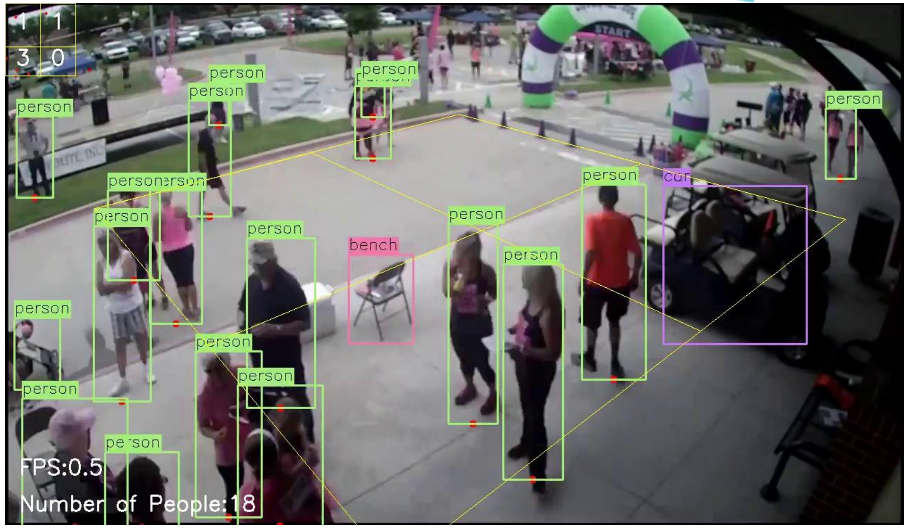
Crowd Counting in Outdoors

- A challenging computer vision problem due to:
  - Heavy occlusion
  - Perspective distortion
  - Scale variation
  - Diverse crowd distribution



Crowd Density Methods – MSFANet & DM-Count

- Crowd counting algorithms predict a density map from a crowd image. Summation of the density map is the crowd count.
- Each training image contains multiple people, each person is annotated by a dot.
- MSFANet crowd counting method
  - Combination of multi-scale-aware modules and dual path decoder
    - Predicts density maps and attention maps for highlighting crowd regions in input image.
  - Uses a Gaussian kernel to smooth each annotated dot.
  - Is trained on L2 pixel-wise loss.
    - Sensitive to the choice of variance in the Gaussian kernel.
- DM-Count crowd counting method
  - Considers density maps and dot maps as probability distributions.
  - Loss composed of optimal transport (OT) loss, total variation (TV) pixel-wise loss & counting loss (CL).

Multi-Scale Feature Adaptive Network (M-SFANet) – Data Preprocessing

Convolve the head annotation with Gaussian kernel (G) which has fixed standard deviation (σ).

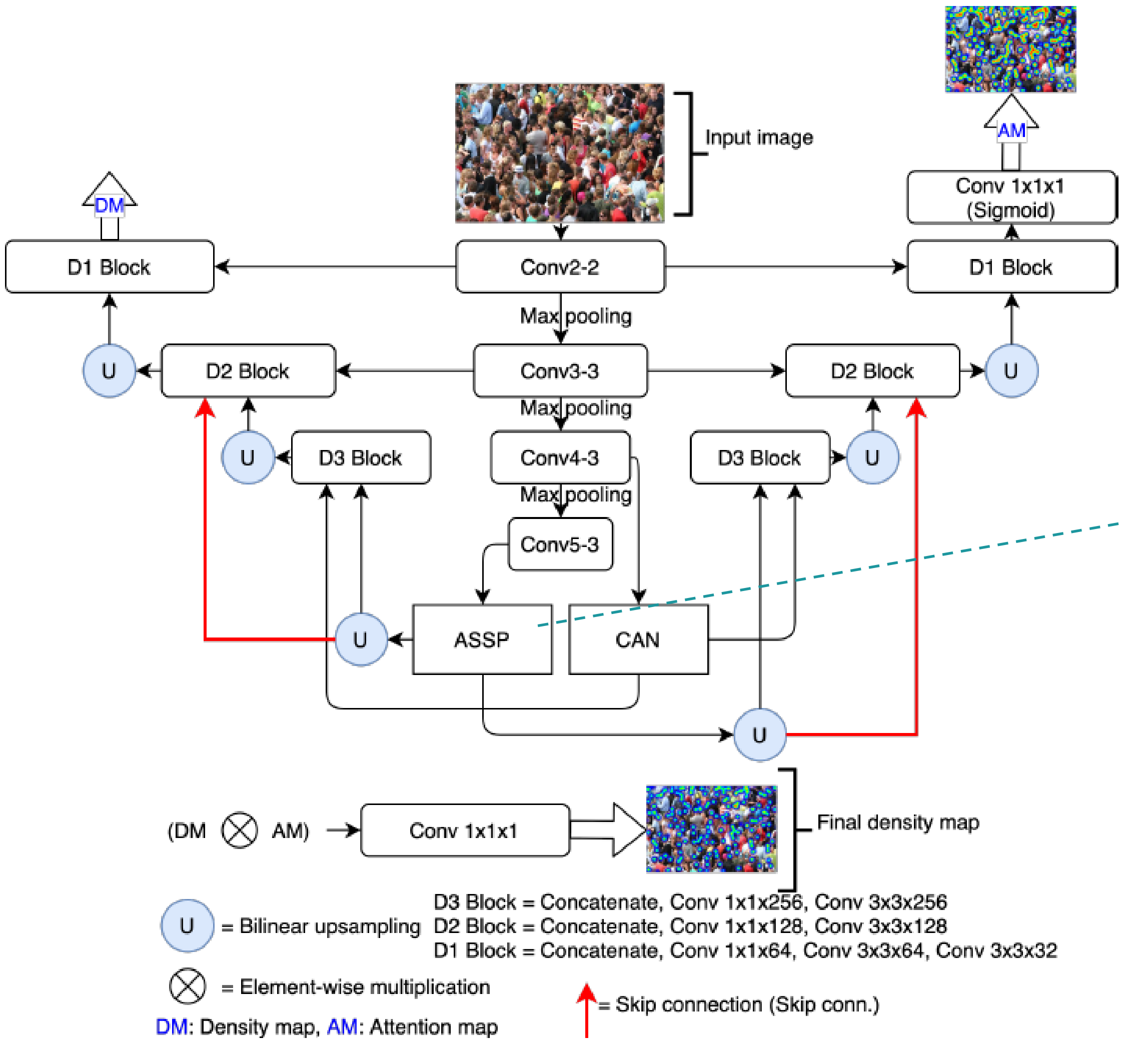
Assuming a head annotation at pixel x_i, represented as $\delta(x - x_i)$,

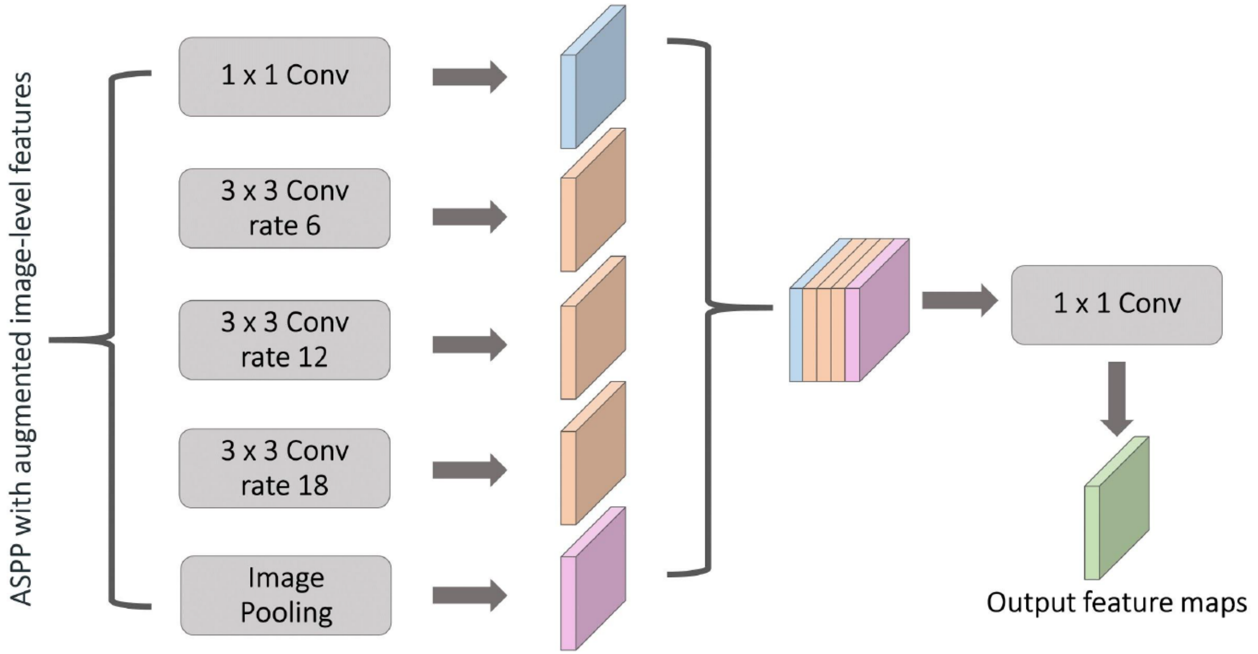
$$\text{density map}, D(x) = \sum_{i=1}^{N} \delta(x - x_i) * G_\sigma(x)$$

where N = total number of headcounts.

$$\text{attention map}, A(i) = \begin{cases} 0 = 0.001 > D(i) \\ 1 = 0.001 \leq D(i) \end{cases}$$

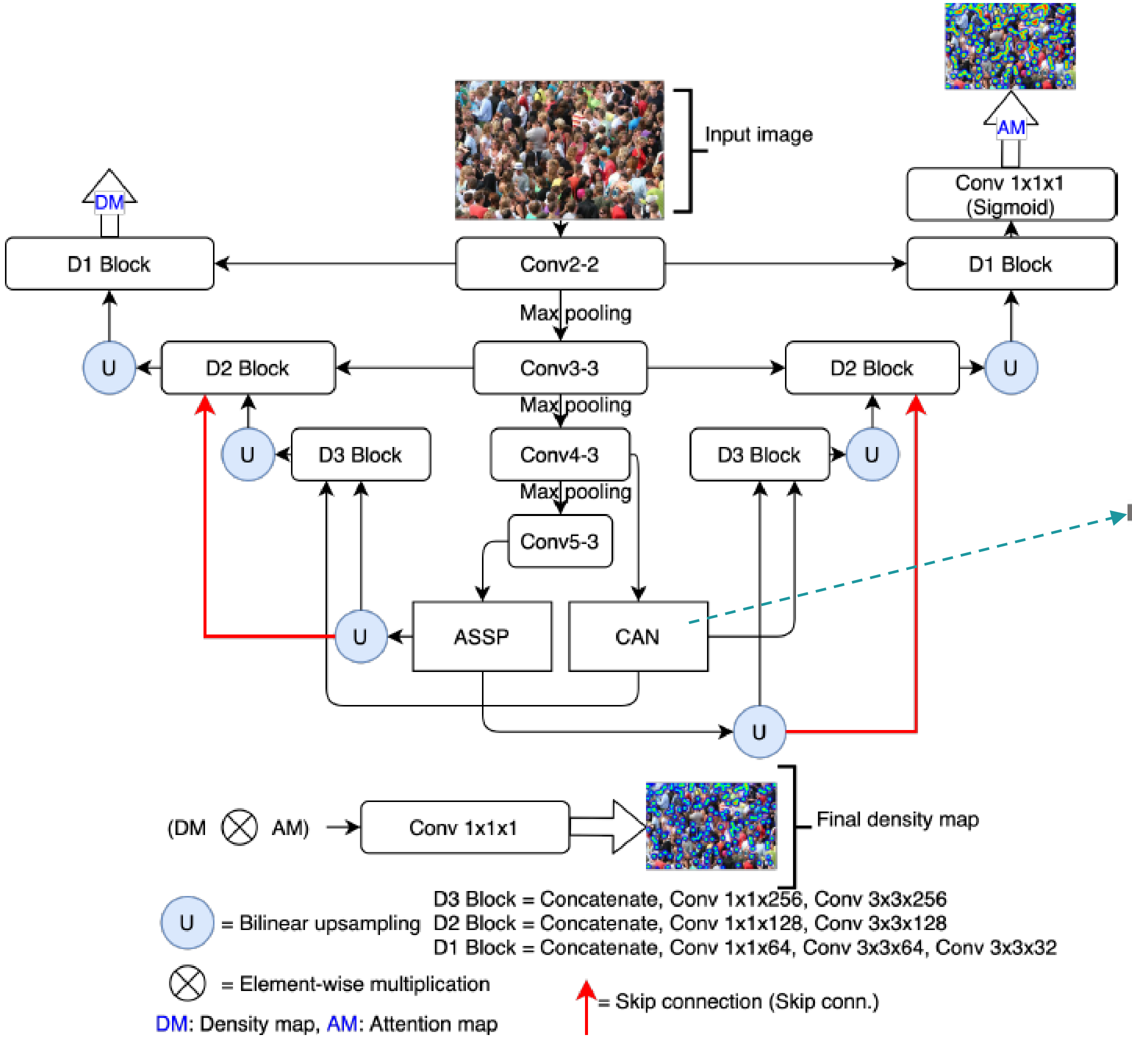
M-SFANet Architecture (1)

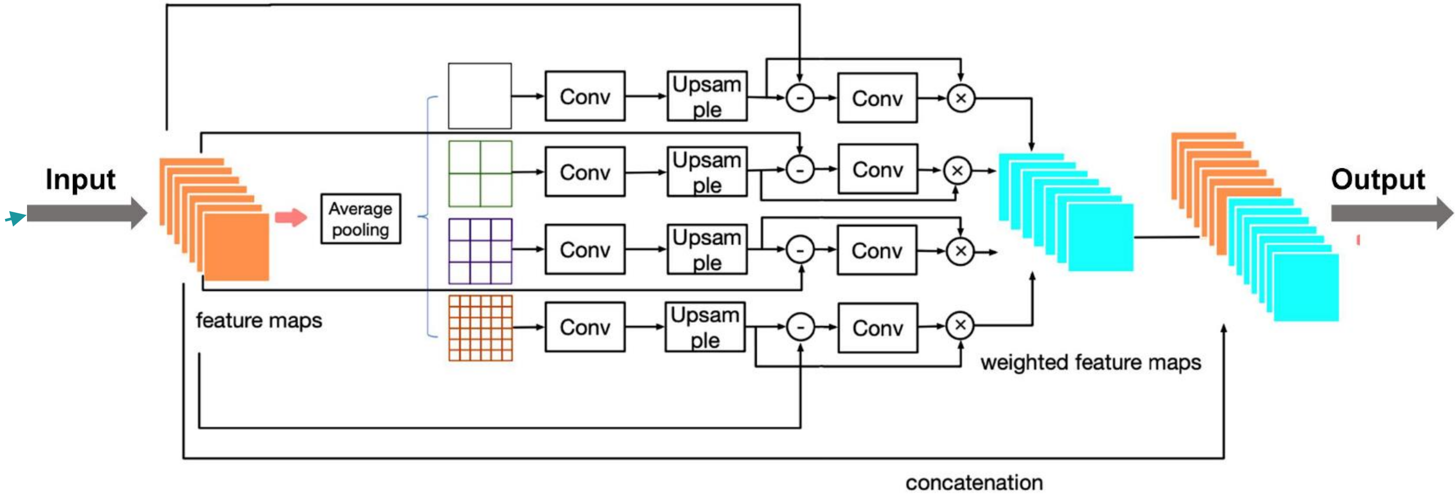




Atrous spatial pyramid pooling (**ASPP**) with augmented image-level features

M-SFANet Architecture (2)

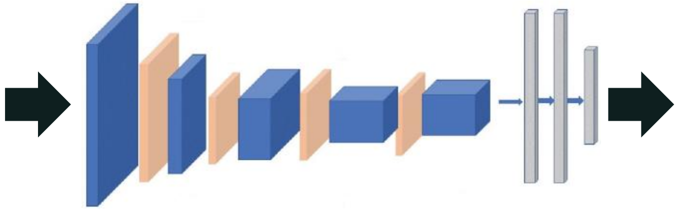




Context-aware module (CAN)

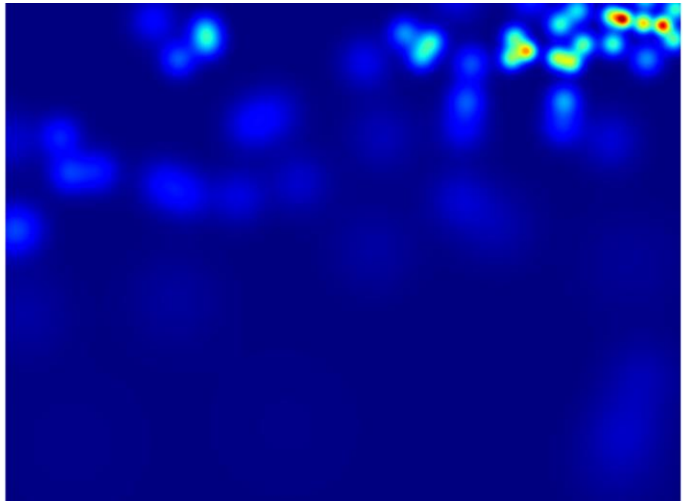
Crowd Counting in Outdoors – DM Count Estimation

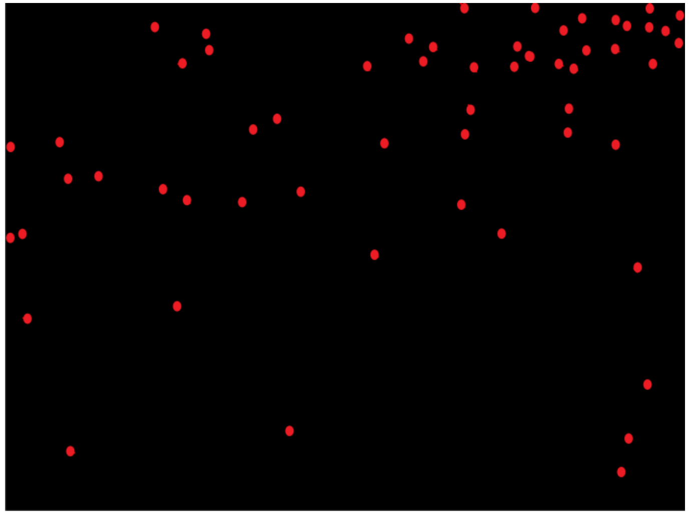
Input Image



VGG19 model

Predicted Density Map





Annotations (Ground Truth Count = 54)

How to measure discrepancy for training?

- Almost all previous work converts the sparse point annotation into dense ground truth maps.
  - Each point is replaced by a gaussian blob.
- DM-Count paper shows that imposing Gaussians to annotations hurts generalization performance.

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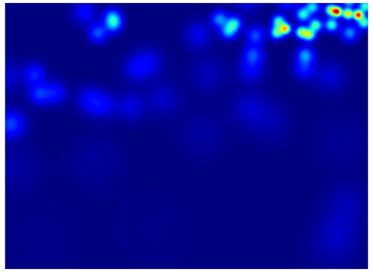
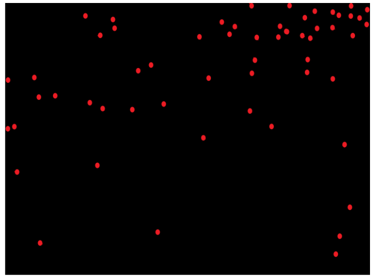
DM-Count Loss



Predicted density map

↓

Source distribution



Sparse annotations

↓

Target distribution

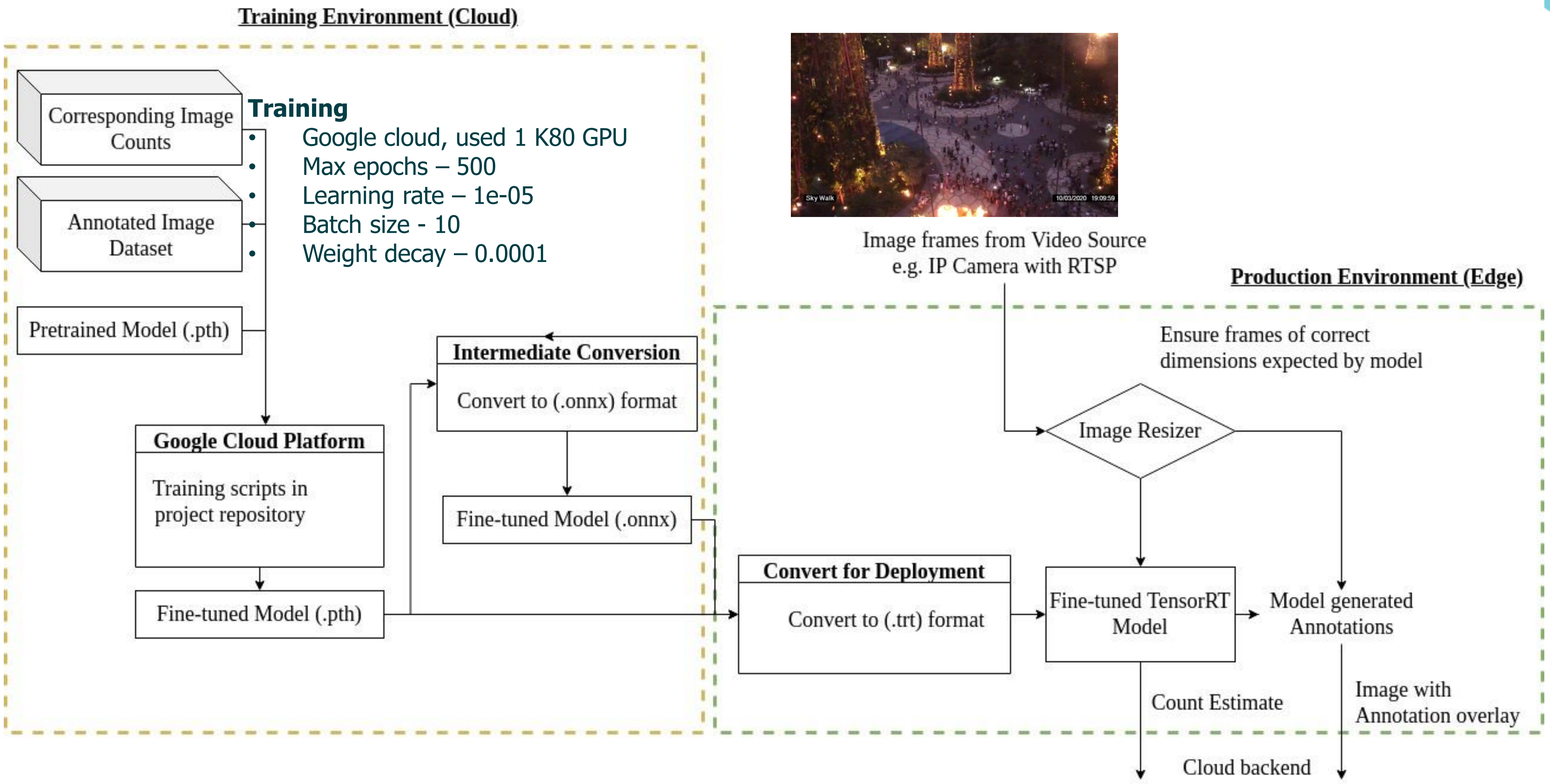
Distribution distance

- DM-Count considers density map as distributions.
- Use of Optimal Transport (OT) to compute the distance between density maps.

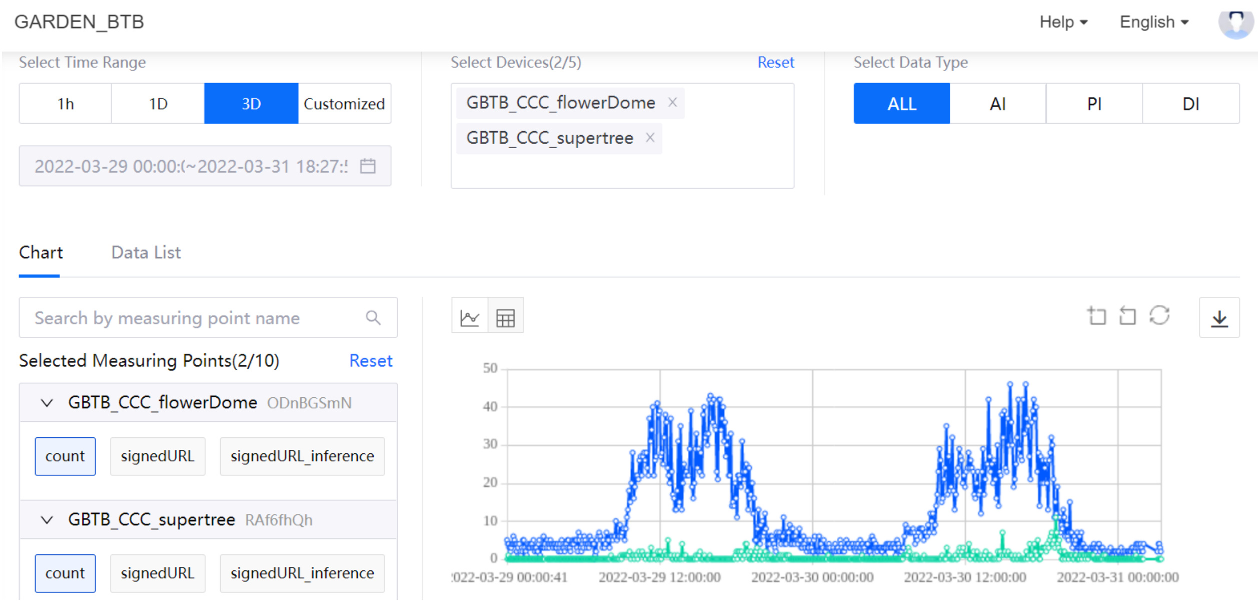
Total loss, $l(\boldsymbol{Y}, \widehat{\boldsymbol{Y}}) = l_C(\boldsymbol{Y}, \widehat{\boldsymbol{Y}}) + \lambda_1 l_{OT}(\boldsymbol{Y}, \widehat{\boldsymbol{Y}}) + \lambda_2 ||\boldsymbol{Y}||_1 l_{TV}(\boldsymbol{Y}, \widehat{\boldsymbol{Y}})$

- Counting loss (l_C): absolute loss between ground truth and predicted counts
- The Optimal Transport loss (l_{OT}): The OT similarity measurements provide valid gradients that can train a network if the source distribution does not overlap with the target distribution.
- Total Variation loss (l_{TV}): Improve stability when optimising the OT loss with the Sinkhorn algorithm.

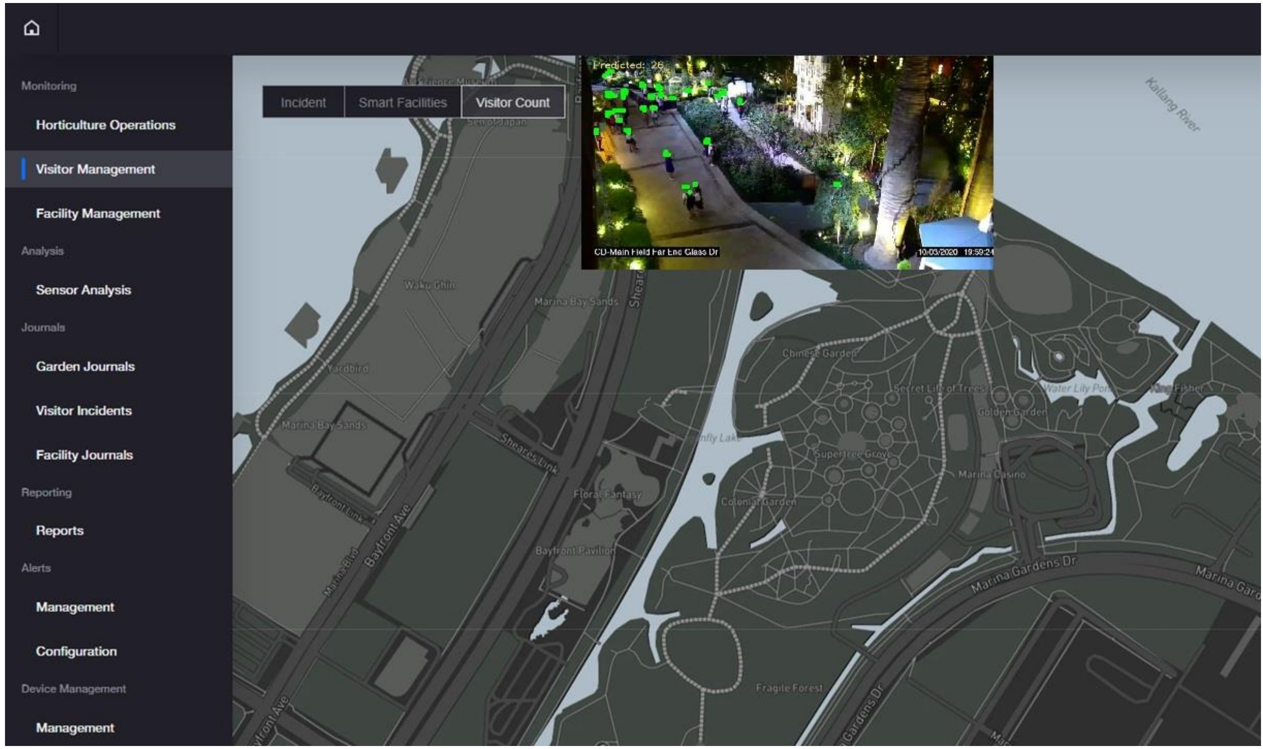
People Counting Outdoors - Workflow



People Counting Outdoors - Cloud Backend and UI



Cloud Backend



User Interface

Crowd Counting Outdoors – Hardware & Software

AAEON Boxer-8253AI

- Nvidia Jetson Xavier NX
- 8GB LPDDR4x
- Storage option: 16GB eMMC and 64GB MicroSD
- GbE PoE/PSE LAN x 2
- Quectel EP06: LTE-A Cat 6 module with Mini PCIe form factor

Model	DM-Count	MSFANet
Dataset	UCF QNRF, Custom	UCF QNRF, Custom
Framework	Pytorch 1.2	Pytorch 1.2
Model optimization	TensorRT (FP16)	TensorRT (FP16)

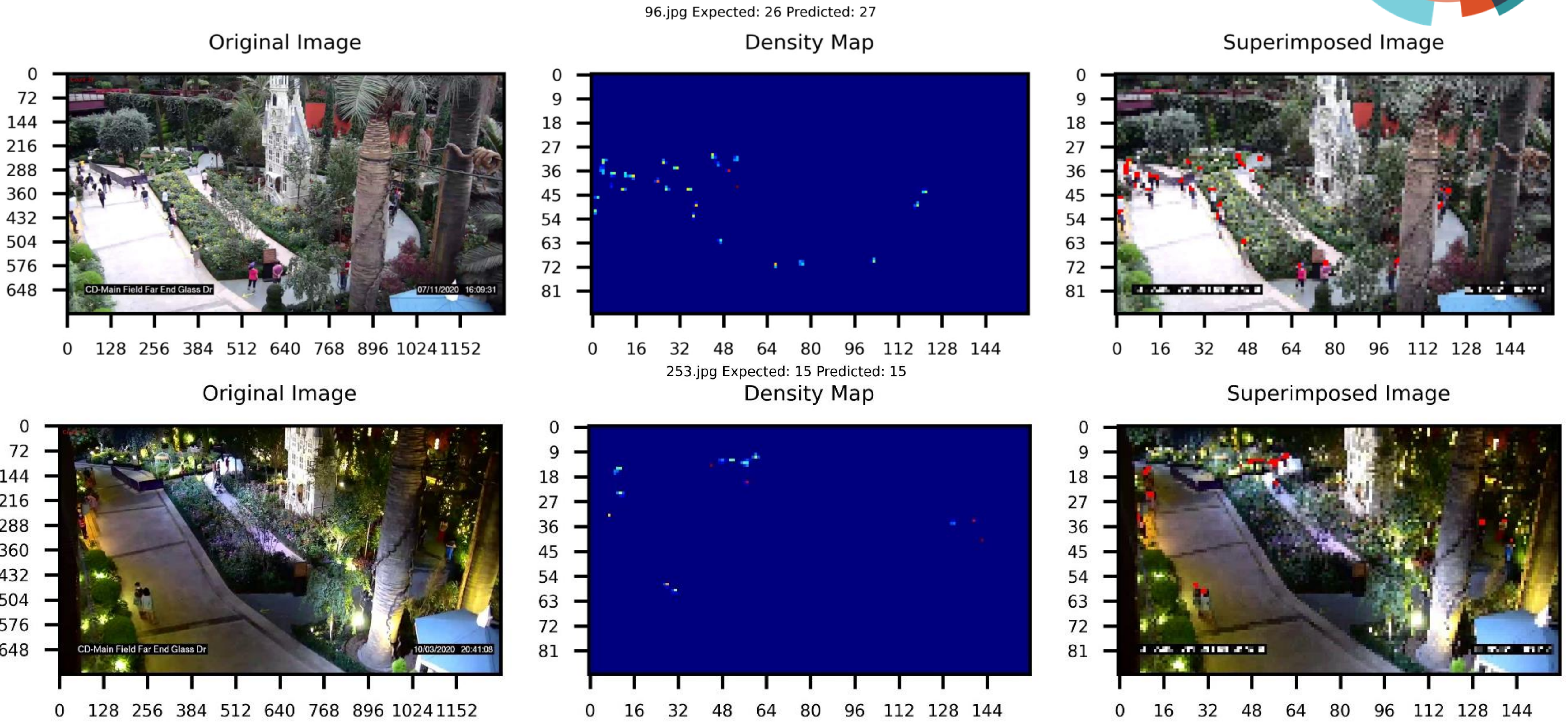
Model	Accuracy (%)	Latency (sec)
DM-Count	92.10	3.467
M-SFANet	88.99	8.841

Pytorch Model on Nvidia Jetson Xavier NX

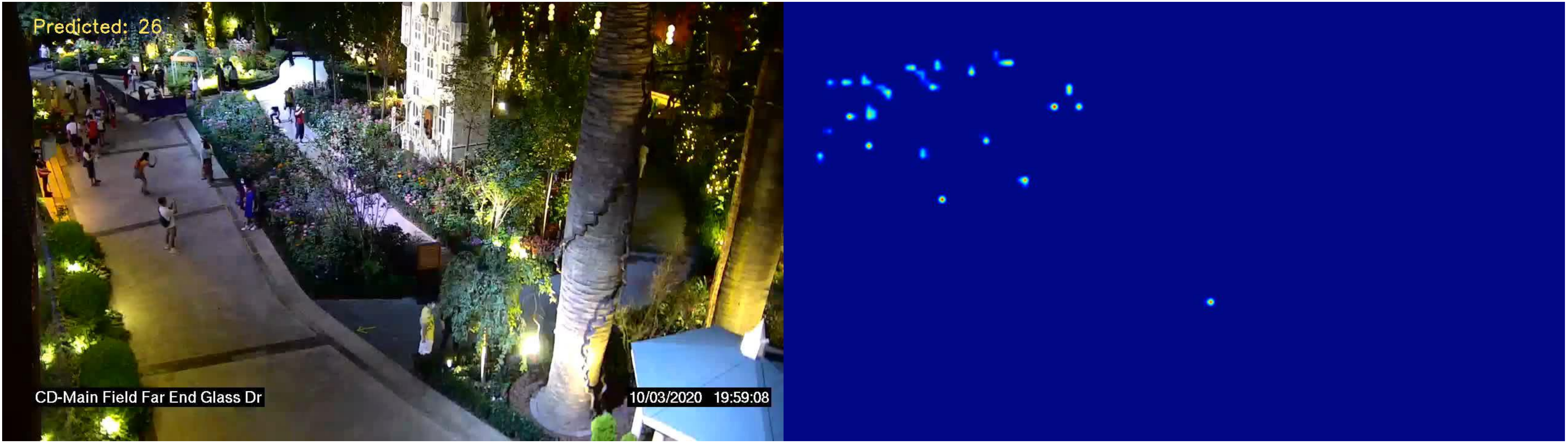
Model	Accuracy (%)	Latency (sec)
DM-Count	91.08	0.380
M-SFANet	86.46	0.637

TensorRT (FP-16) on Nvidia Jetson Xavier NX

Crowd Counting Outdoors – Results



Crowd Counting in Outdoors – DM-Count Results



Summary

- Accurate people counting:
  - For indoor environments, is almost a solved problem, when there are less/no occlusions.
  - For outdoor environments, is a challenging problem due to:
    - Heavy occlusion
    - Perspective distortion
    - Scale variation
    - Diverse crowd distribution
  - DM-Count performed well even with occlusions, providing accurate counts.

Resources

Sensors & IoT Department

https://www.tech.gov.sg/capability-centre-siot

Government Technology Agency of Singapore (GovTech)

https://www.tech.gov.sg

M-SFANet for Count Counting (original paper and code)

https://arxiv.org/abs/2003.05586

https://github.com/Pongpisit-Thanasutives/Variations-of-SFANet-for-Crowd-Counting

Distribution Matching for Count Counting (original paper and code)

https://arxiv.org/abs/2009.13077

https://github.com/cvlab-stonybrook/DM-Count