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Multi-Camera Tracking for Employee Behavior Monitoring

Trần Quốc Lập – 20194443

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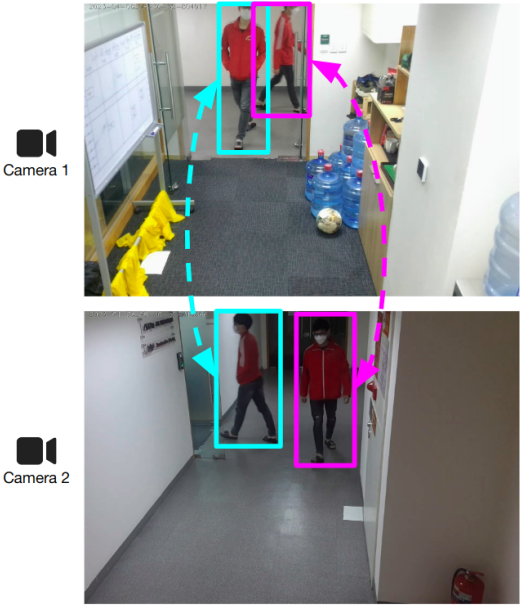
ONE LOVE. ONE FUTURE

INTRODUCTION & OBJECTIVE

Multi-camera tracking (MCT) aims to track people across cameras.

MCT has various applications. In employee management, MCT can track and monitor employee behaviors.

Example: Amazon's worker surveillance



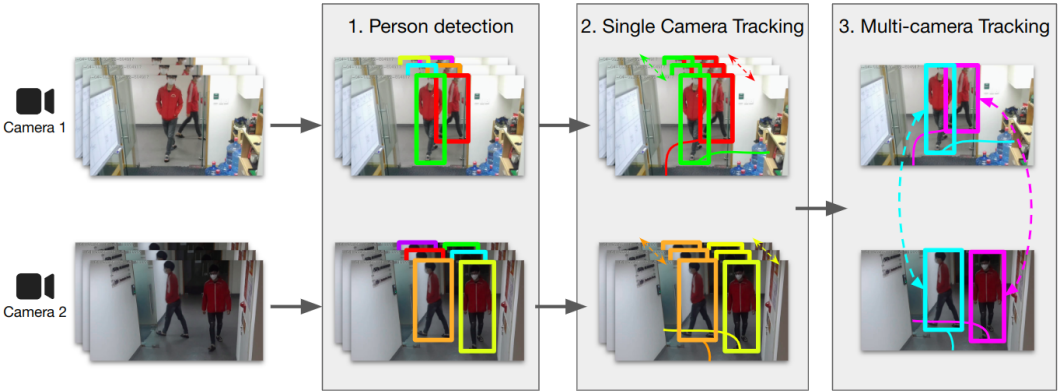
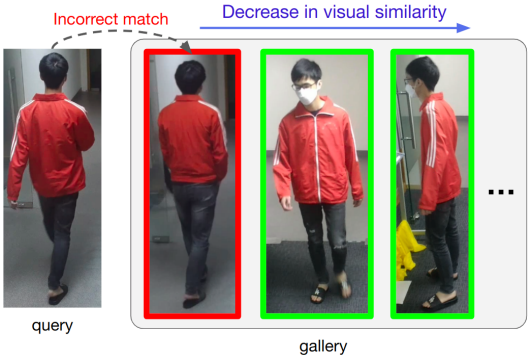


Figure 1: General pipeline for multi-camera tracking.

1. Person detection: Detect person in single frame (e.g. YOLOv3, YOLOv7).
2. Single camera tracking: Match boxes to form tracks (e.g. SORT, ByteTrack).
3. Multi-camera tracking: Match tracks across cameras.

To match tracks across cameras, popular methods compare people visual appearance, notably Re-ID.

Issue of Re-ID: easily matches incorrectly if people (e.g. employees) wear uniforms.



Thesis work: develop a MCT solution that can work well when people have similar appearance.

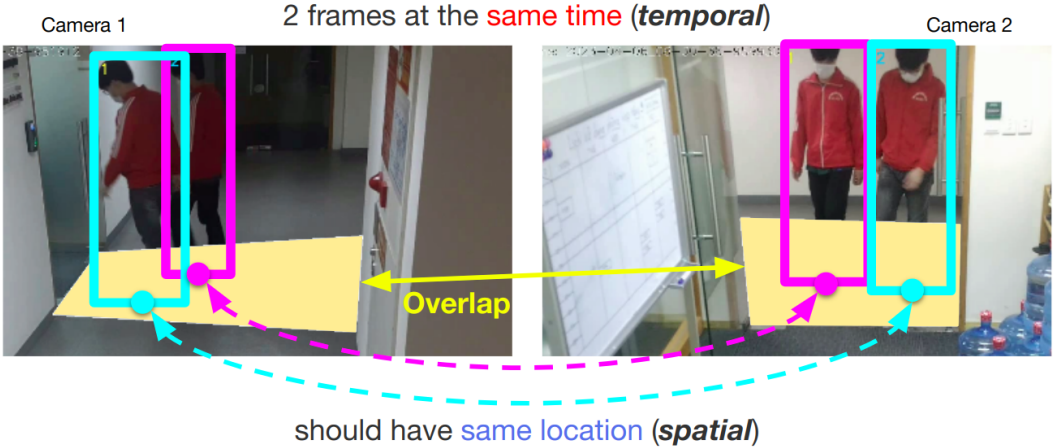


Figure 2: Proposed: MCT based on Spatio-Temporal Association (STA) with overlapping area.

Scope:

- ◇ Small overlap & synchronized cameras.
- ◇ Track employees wearing uniforms.
- ◇ Maximum 4 people.
- ◇ 3 cameras.

$\Longrightarrow$ no public dataset

$\Longrightarrow$ collect 36 videos, split into 3 sets that vary in moving direction and number of people gathering at the overlapping area: Easy (2 people), Medium (3 people), Hard (4 people).

Figure 3: Camera setup and FOV

PROPOSED METHOD & EVALUATION

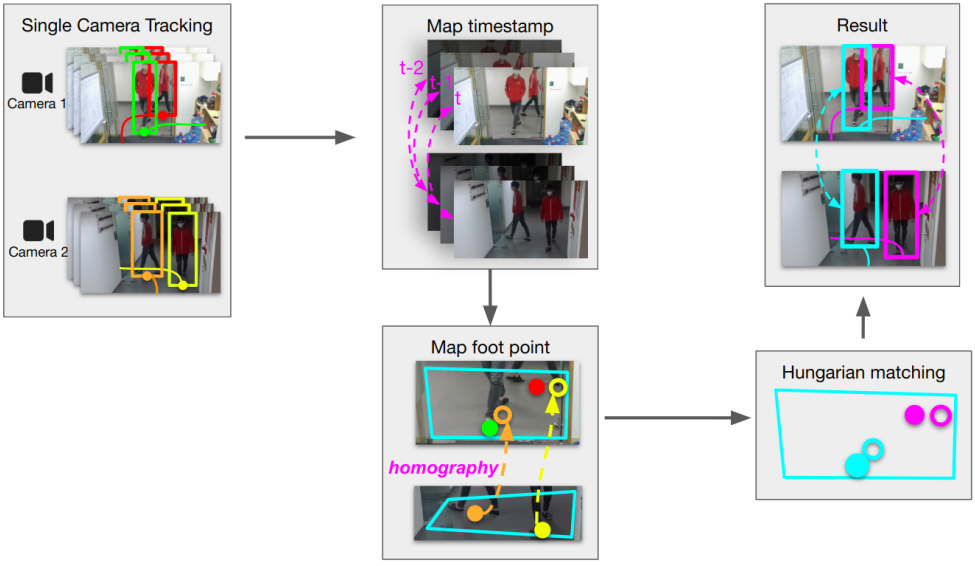


Figure 4: Overview of the proposed STA method.

Evaluation metric:

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}, \qquad \text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}, \qquad \text{F1} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

Video set	#TP	#FP	#FN	F1
Easy	511	7	7	0.986
Medium	662	46	22	0.951
Hard	966	144	41	0.913
Total	2139	197	70	0.941

Table 1: **TP**: correctly matched pair. **FP**: incorrectly matched pair. **FN**: missed pair.

- ◇ Promising but decreases with complexity.
- ◇ #FP >> #FN, especially with hard and medium sets.

Figure 5: With Re-ID, all individuals wearing uniform are considered the same person.

Video set	Re-ID	**STA**
Easy	0.5 (32 - 64 - 0)	1.0 (32 - 0 - 0)
Medium	0.348 (57 - 211 - 2)	0.982 (57 - 0 - 2)
Hard	0.380 (54 - 176 - 0)	0.991 (53 - 0 - 1)

Table 2: Re-ID vs. the proposed STA. Each cell format is F1(#TP, #FP, #FN) evaluated at track-level.

The proposed baseline method outperformed Re-ID in 3 datasets where people have similar appearance.

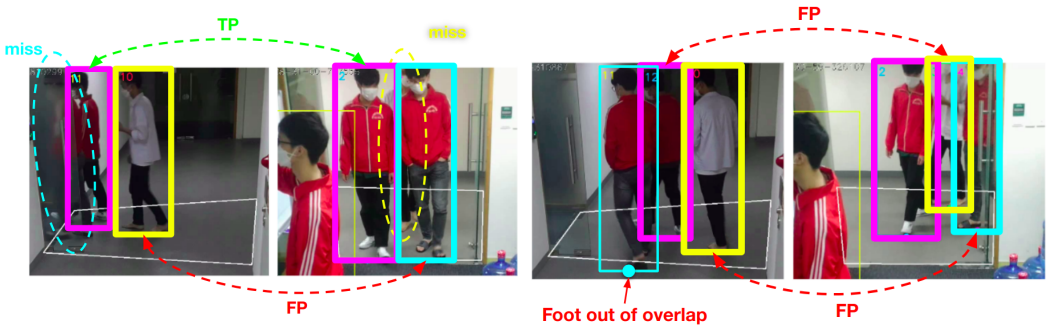
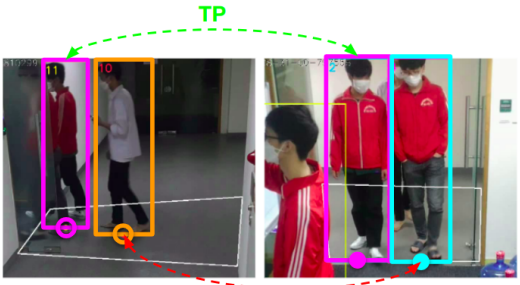
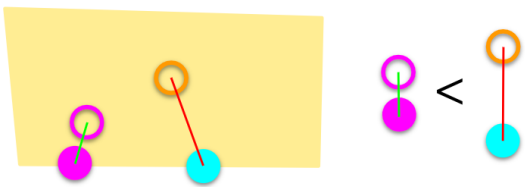


Figure 6: Two main causes of FP and FN:
a) missing detection.
b) incorrect foot interpolation.

Assumption: FP due to missing detections have larger spatial distance than TP.
$\Longrightarrow$ treated those FP as outliers in the distance distribution.





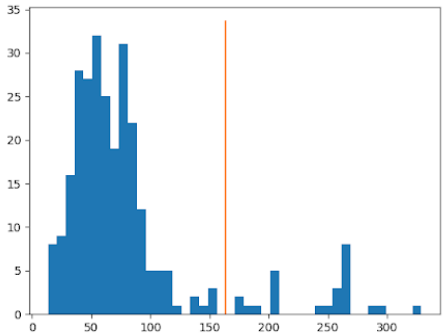


Figure 7: Distance distribution of matched pairs. x-axis: distance. y-axis : #matched pairs. Seam: upper bound by IQR(25, 75).

Assumption: Sometimes a mismatch (FP and FN) can be solved by taking matches in previous and next timestamps into account

$\Longrightarrow$ average distance over neighboring frames as an input cost for the Hungarian.

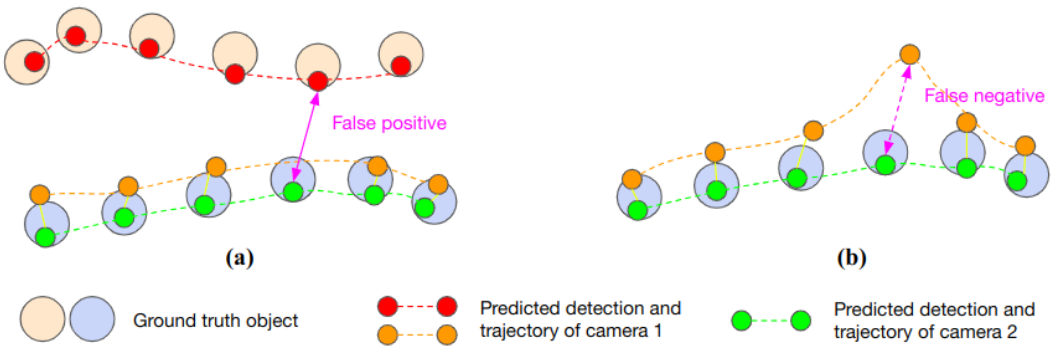
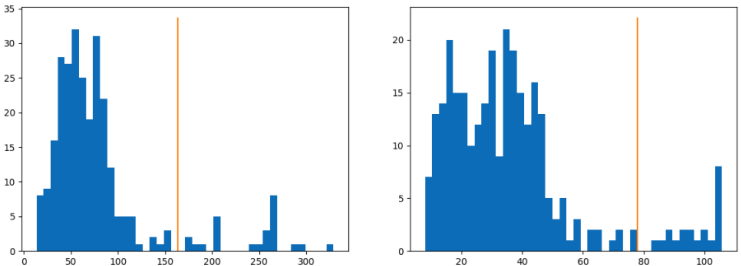


Figure 8: window-based mapping may reduce **a)** FP and **b)** FN.

Issue with rectangular bounding box: Even if it fits the body well, the foot point (midpoint of bottom edge) may not be accurate. E.g: when legs apart.



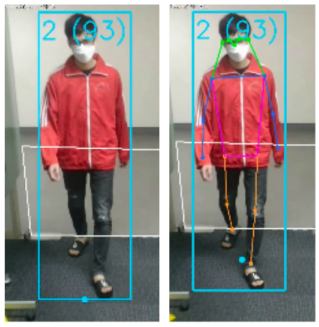


Figure 9: Distance distribution. **a)** using box. **b)** using pose.

Experiments prove that using pose:

- ◇ gives more accurate foot points.
- ◇ must combine with FP filtering, or else it will be worse than using box.

Set	Baseline	FP filtering (1)	Window-based (2)	(1) + $(2)^*$	$(1)^*$ + $(2)^+$ + Pose
Easy	0.986 (511,7,7)	0.983 (507,7,11)	**0.994** (515,3,3)	0.986 (509,5,9)	0.985 (657,3,17)
Medium	0.951 (662,46,22)	0.958 (658,32,26)	0.955 (665,43,19)	0.969 (662,20,22)	**0.991** (886,8,8)
Hard	0.913 (966,144,41)	0.927 (959,103,48)	0.921 (975,135,32)	0.938 (963,83,44)	**0.960** (1179,36,63)
Total	0.941 (2139,197,70)	0.949 (↑ 0.8%) (2124,142,85)	0.948 (↑ 0.7%) (2155,181,54)	0.959 (↑ 1.9%) (2134,108,75)	**0.976** (↑ 3.7%) (2722,47,88)

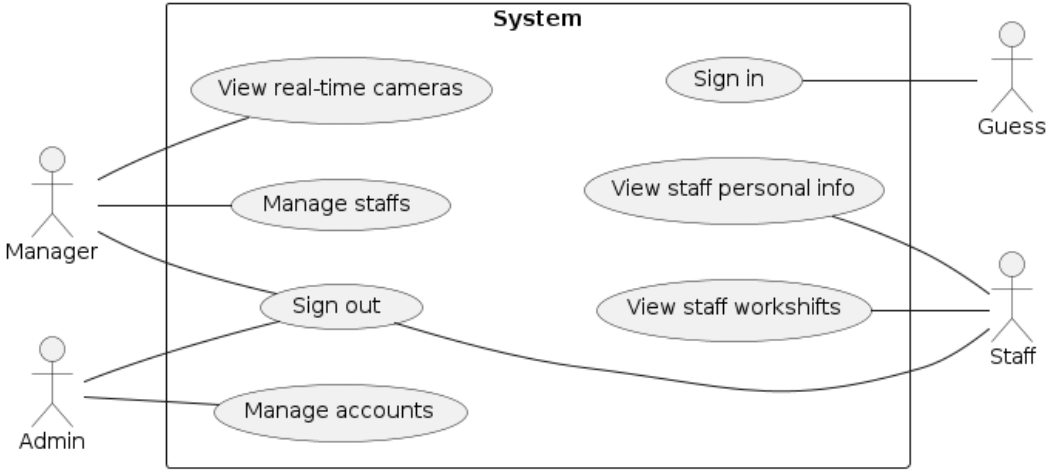
Table 3: Each cell format is F1(#TP, #FP, #FN) evaluated at frame-level. (1): IQR(20, 80). (2): window-size = 15. $(1)^*$: IQR(25, 75). $(2)^*$: window-size = 11. $(2)^+$: window-size = 7.

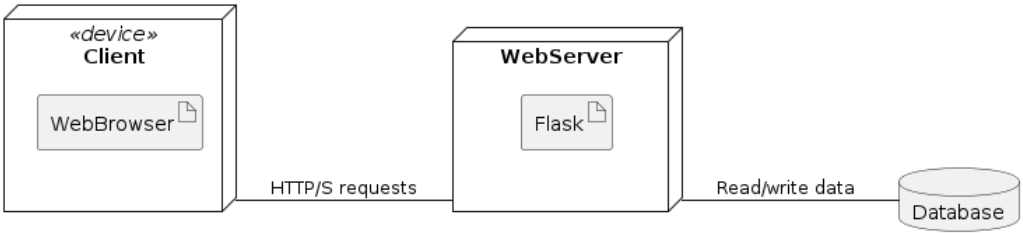
In general, all the extensions have greater and positive impact on complex cases than on easy cases.

- ◇ The proposed Spatio-Temporal Association outperformed visual-based Re-ID in 3 datasets where people have similar appearance.
- ◇ Enhancements:
  - address missing detection: FP filtering and window-based mapping (↑ 1.9%).
  - address inaccurate footpoint: Pose estimation but need FP filtering to be applied (↑ 3.7%)
- ◇ Those extensions have more impact on complex cases.

APPLICATION SYSTEM DEVELOPMENT

Application: Develop a software system to showcase the applicability and demand for the proposed solution.



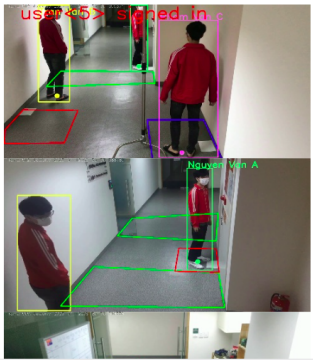


Frameworks used in research and developments:

- ◇ Machine learning and Computer Vision:
  - ○ NumPy, Scikit-Learn, SciPy.
  - ○ PyTorch, OpenCV.
- ◇ Web development: Flask, SQLite.

Employee Management

Camera view



Employee Management

Productivity report: Nguyen Van A

Day	Date	Day shift	Arrival	Staying time
Wednesday	12/04/2023	morning	08:30:20 (a few seconds late)	19
Tuesday	11/04/2023	morning	08:30:11 (a few seconds late)	68.9%
Monday	10/04/2023	morning	08:30:19 (a few seconds late)	66.4%
Friday	07/04/2023	morning	08:30:02	61.4%

Employee Management

Messages

9 minutes ago
Tran Van B was absent from work area since 08:31:04

9 minutes ago
Tran Van B is back to work area at 08:30:58

9 minutes ago
Tran Van B was absent from work area since 08:30:34

9 minutes ago
Pham Van C is back to work area at 08:30:38

9 minutes ago
Pham Van C was absent from work area since 08:30:29

9 minutes ago
Tran Van B is back to work area at 08:30:33

9 minutes ago
Pham Van C arrived late at 08:30:29

Contributions:

- ◇ A Spatio-Temporal Association for MCT that outperformed Re-ID when people have similar appearance.
- ◇ Extensions that incrementally improved the proposed method.
- ◇ A software system that showcased the applicability of the proposed method.

Future works:

- ◇ Investigate the precision of the proposed method on different datasets.
- ◇ Determine the parameters of the extensions automatically that are not specific to any dataset.
- ◇ Develop a solution to combine Re-ID and STA in general MCT problems.