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Multi-Camera Tracking for Employee Behavior Monitoring

Trần Quốc Lập – 20194443

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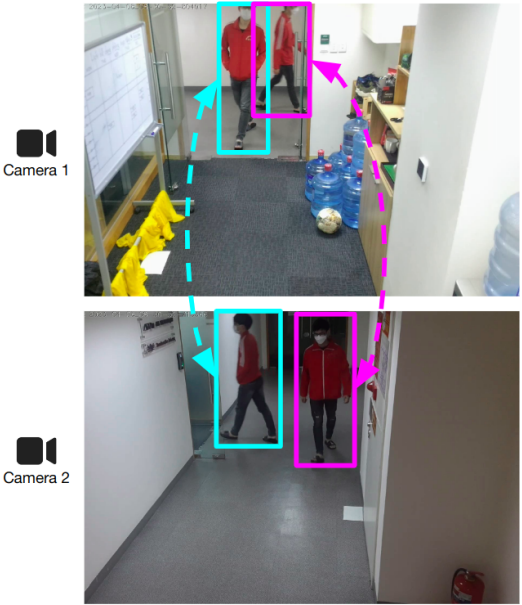
ONE LOVE. ONE FUTURE

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



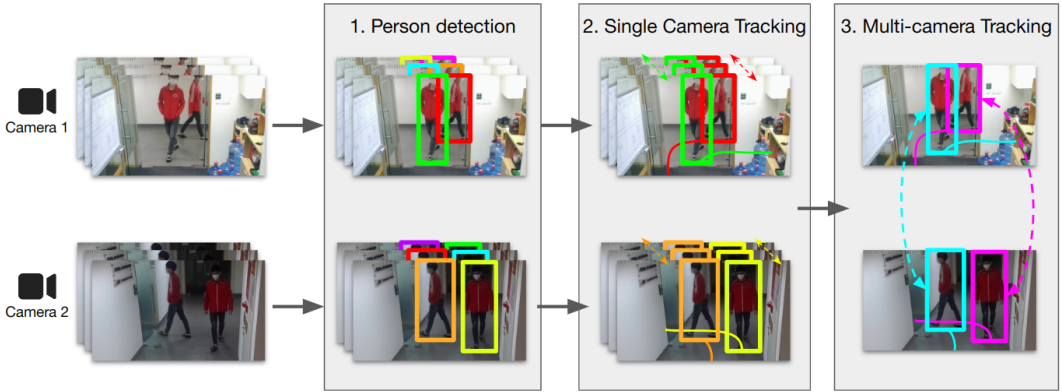
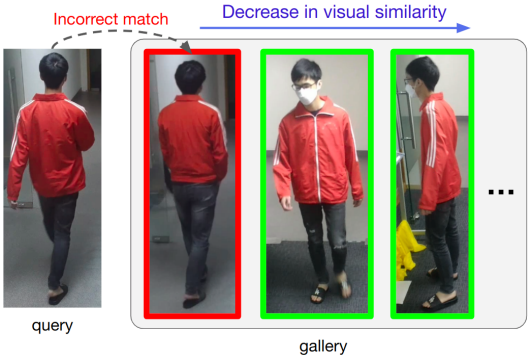


Figure 1: General pipeline for multi-camera tracking.

1. Person detection: Detect person in single frame (e.g. YOLO [3, 2]).
2. Single camera tracking: Match boxes to form tracks (e.g. SORT [1], ByteTrack [4]).
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.

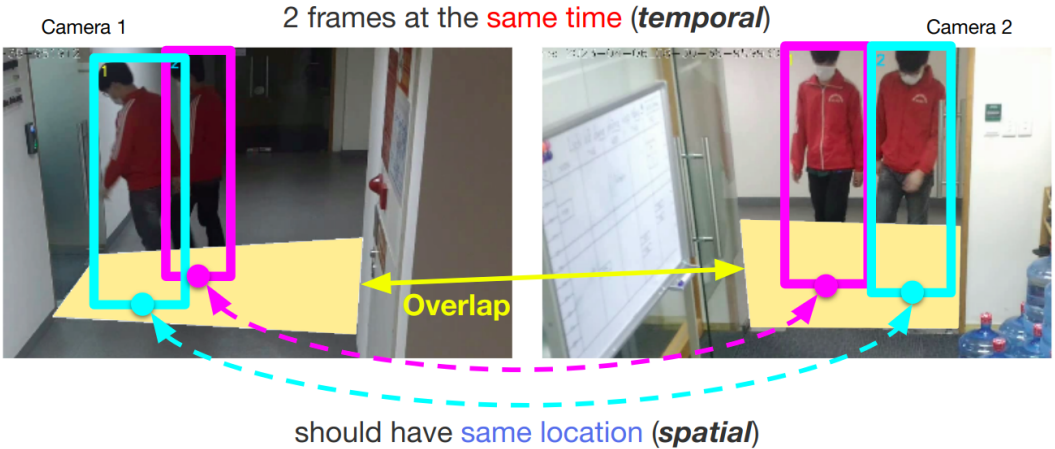


Figure 2: Proposed: MCT based on Spatio-Temporal Association (STA) with overlapping area.

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: Easy, Medium, Hard.

Figure 3: Camera setup and FOV

PROPOSED METHOD & EVALUATION

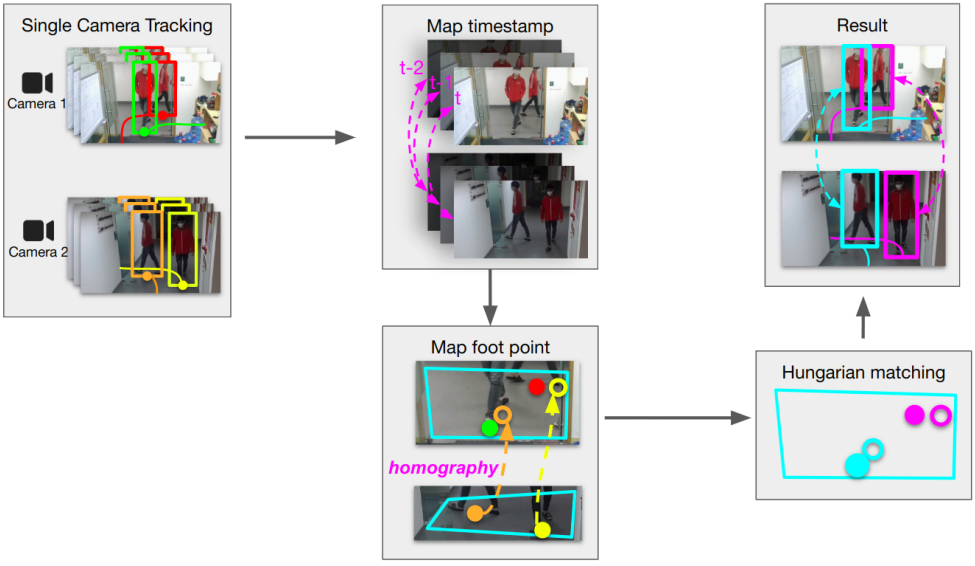


Figure 4: Overview of the proposed STA method.

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.

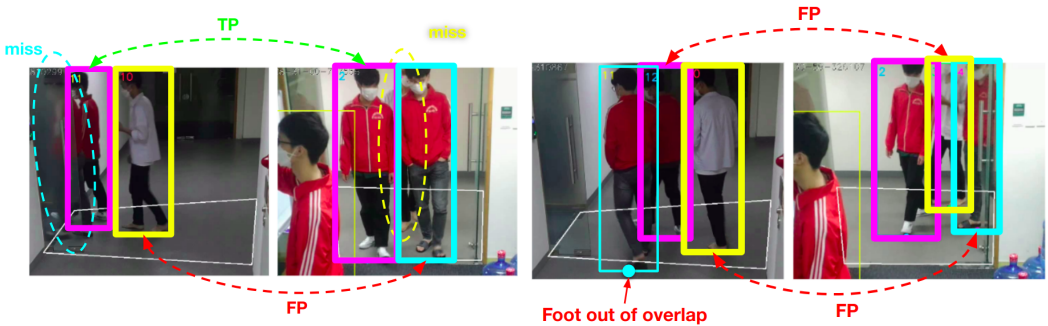
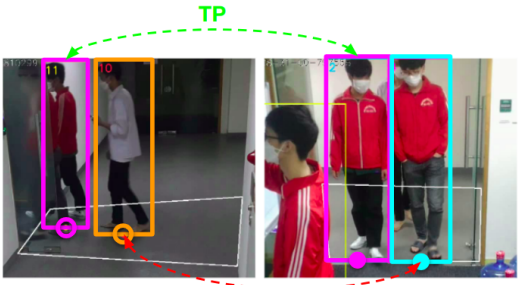


Figure 5: Two main causes of FP and FN:
a) missing detection.
b) incorrect foot interpolation.

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



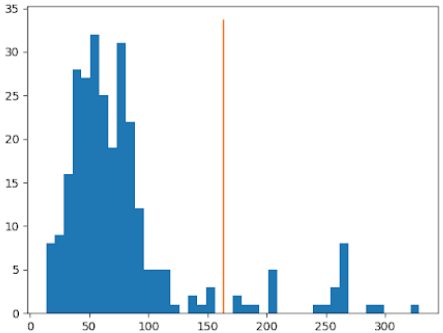


Figure 6: Distance distribution of matched pairs. x-axis: distance. y-axis : #matched pairs. Seam: upper bound by IQR(25, 75).

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.

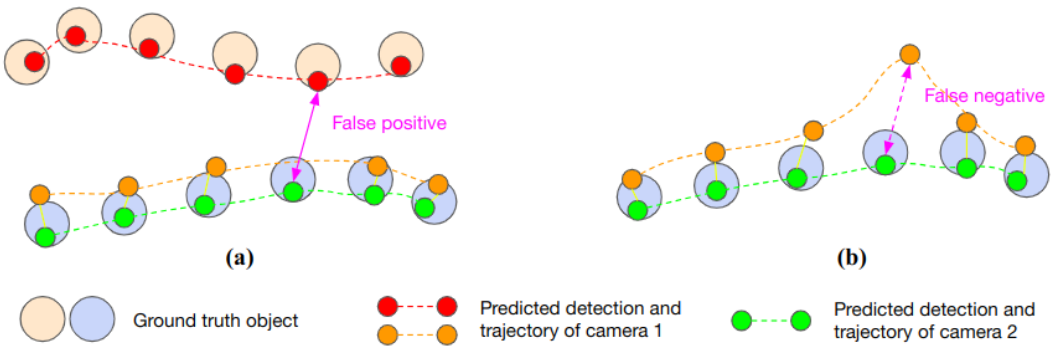
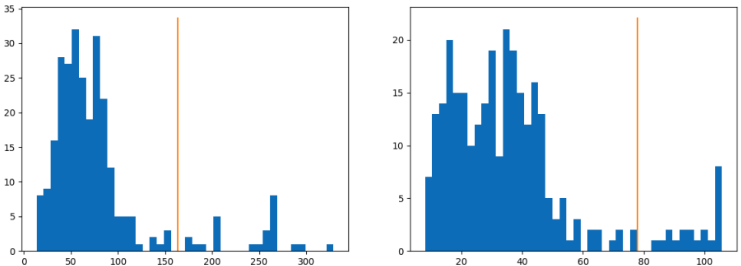


Figure 7: window-based mapping may reduce **a)** FP and **b)** FN.

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.



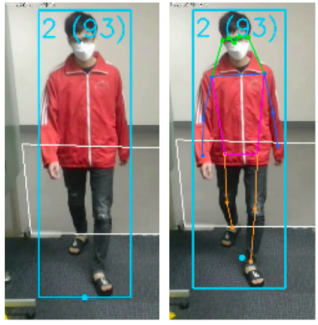


Figure 8: Distance distribution. **a)** using box. **b)** using pose.

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	IQR (20, 80)	size = 15	IQR(20,80) size = 11	**IQR(25, 75) size = 7 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 (2124,142,85)	0.948 (2155,181,54)	0.959 (2134,108,75)	0.976 (2722,47,88)

Table 2: Each cell format is F1(#TP, #FP, #FN) evaluated at frame-level.

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

Figure 9: The matching results using Re-ID.

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)

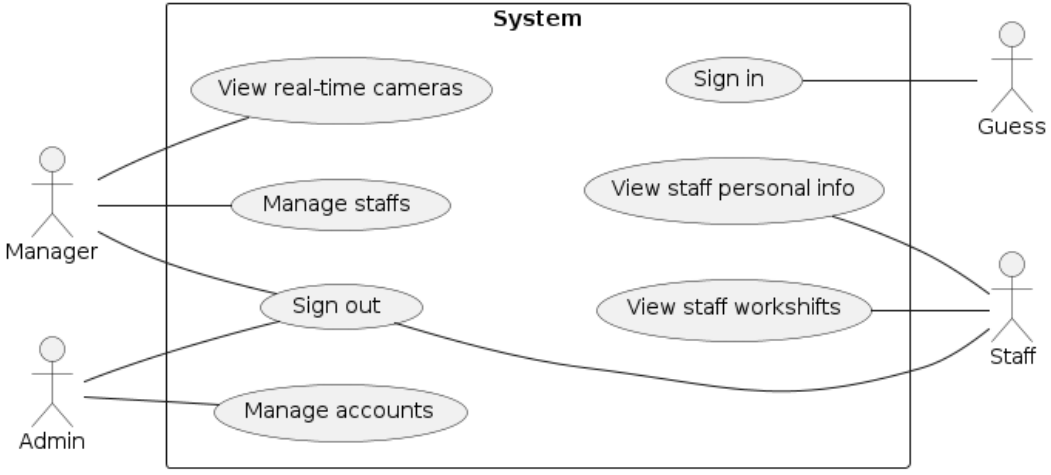
Table 3: Re-ID vs. the proposed STA method evaluated at track-level.

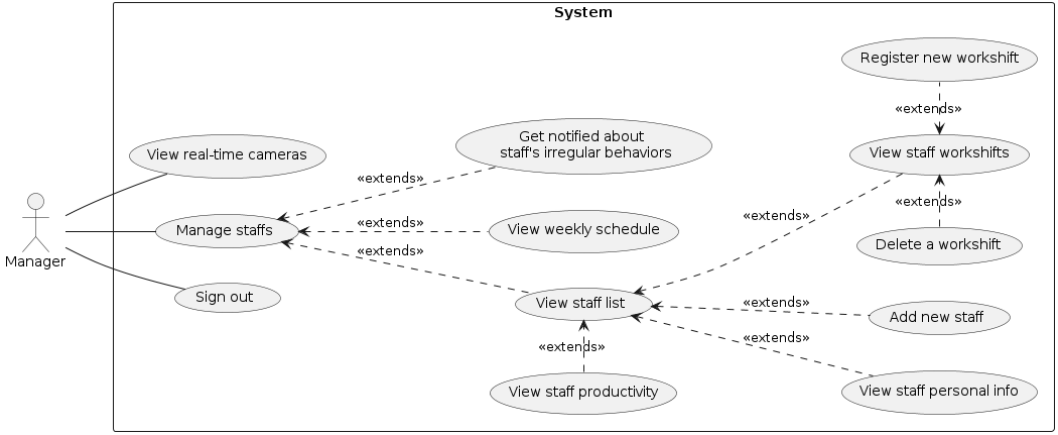
With Re-ID, all individuals wearing the same uniform are considered the same person.

- The proposed Spatio-Temporal Association can associate people in multiple cameras when they have similar appearance.
- Issues:
  - missing detection: improve with FP filtering and window-based mapping.
  - inaccurate foot point interpolation: improve with Pose, but need FP filtering to be applied.
- Those extensions have more impact on complex cases and can be combined to produce a more impressive result.

APPLICATION SYSTEM DEVELOPMENT

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

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View real-time cameras
Manage staffs
Sign out
Get notified about
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View weekly schedule
View staff list
View staff productivity
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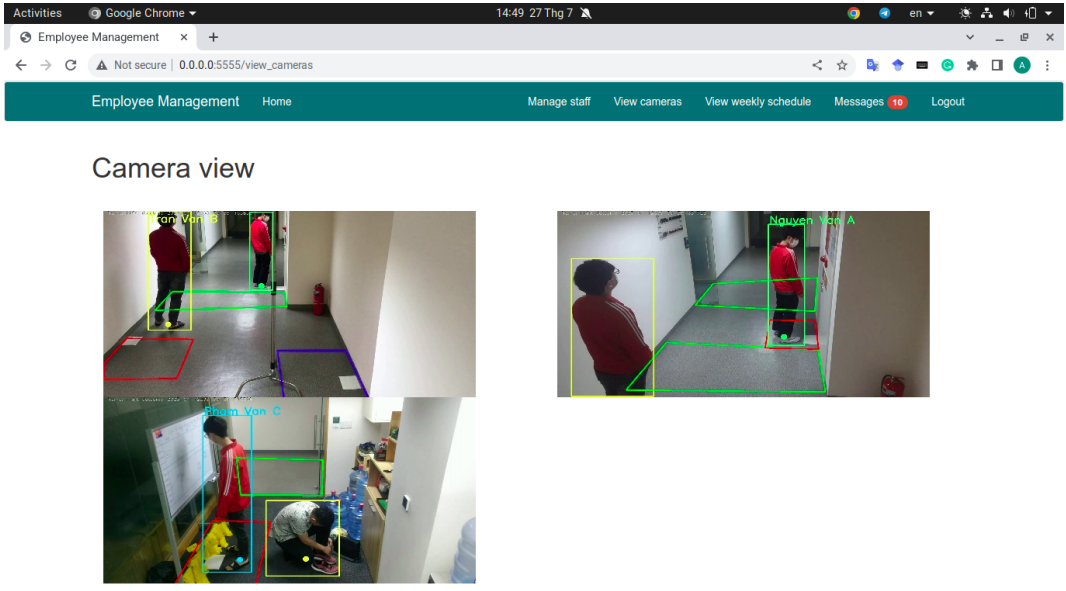
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Messages 10
Logout
Camera view
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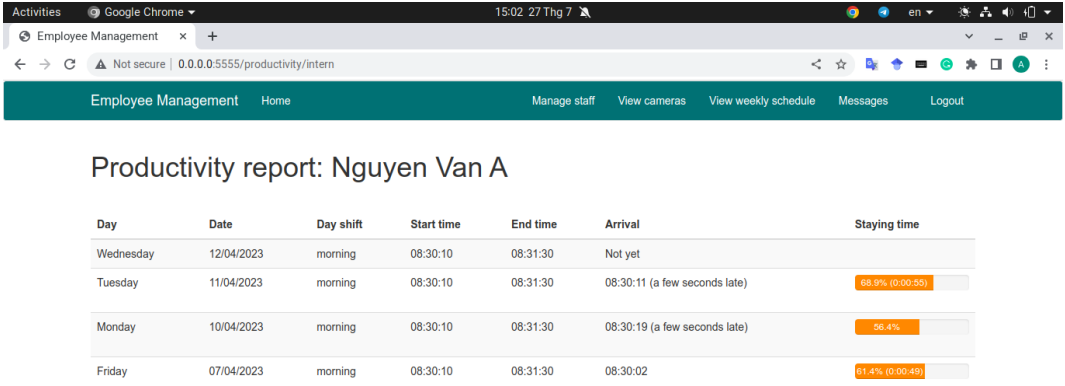
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Arrival
Staying time
Wednesday
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morning
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Not yet
Tuesday
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08:30:11 (a few seconds late)
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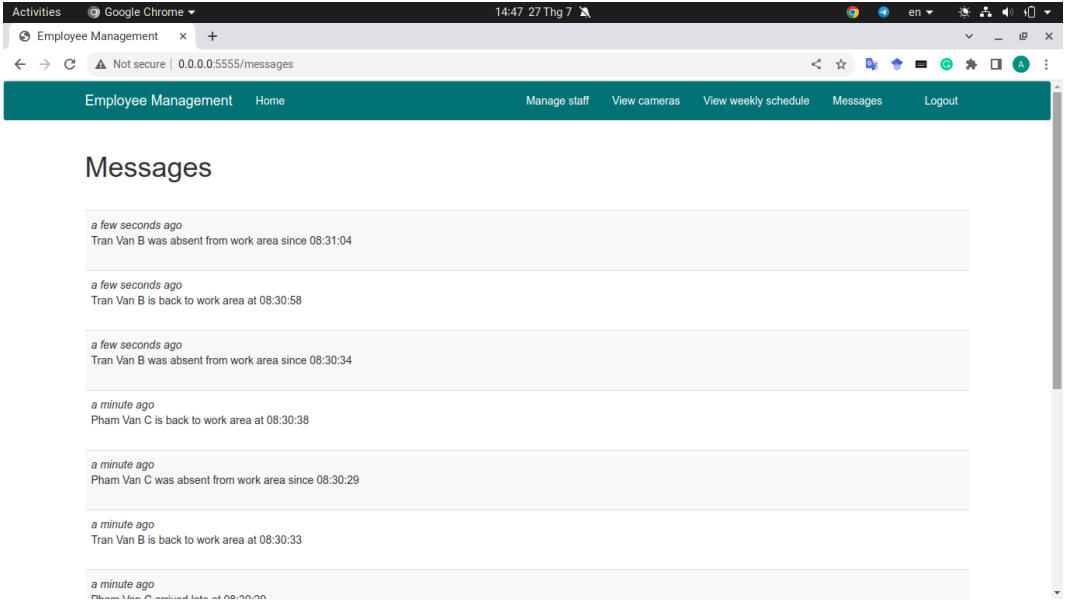
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Employee Management
Home
Manage staff
View cameras
View weekly schedule
Messages
Logout
Messages
a few seconds ago
Tran Van B was absent from work area since 08:31:04
a few seconds ago
Tran Van B is back to work area at 08:30:58
a few seconds ago
Tran Van B was absent from work area since 08:30:34
a minute ago
Pham Van C is back to work area at 08:30:38
a minute ago
Pham Van C was absent from work area since 08:30:29
a minute ago
Tran Van B is back to work area at 08:30:33
a minute ago

Conclusion:

- ◇ A Spatio-Temporal Association for MCT was proposed to replace Re-ID when people have similar appearance.
- ◇ Extensions was incremental introduced to improve the proposed method.
- ◇ A software system was developed to showcase the applicability of the proposed method.

Improvement:

- ◇ Improve limitation is previous step of MCT (person detection, single camera tracking) such as ID switch, missing detection.
- ◇ Optimize software system.


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Simple online and realtime tracking.
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YOLOv7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors.
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Bytetrack: Multi-object tracking by associating every detection box.
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