# Enabling RFID-Based Tracking for Multi-Objects with Visual Aids: A Calibration-Free Solution

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# Object Identification and Tracking

## Background

Checkout-free
shopping

Electronic article
surveillance

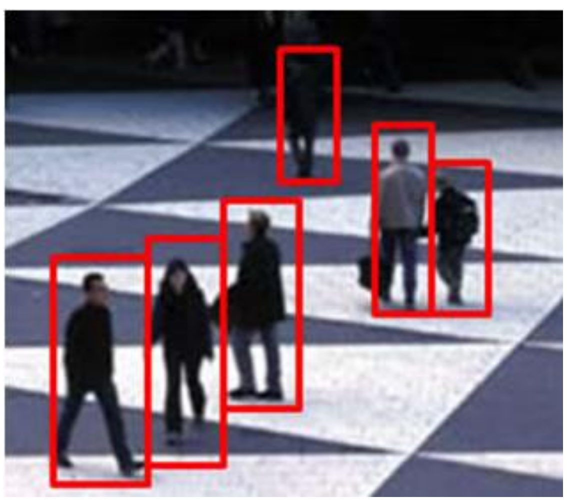
The ability to detect, track and identify multiple objects is crucial in many applications.

# Object Identification and Tracking

## Existing Technologies

**RFID-based localization**

- ✓ Pros: battery-free, non-line-of-sight communication, etc
- ✓ Cons: dedicated devices or massive deployment costs



**CV-based tracking**

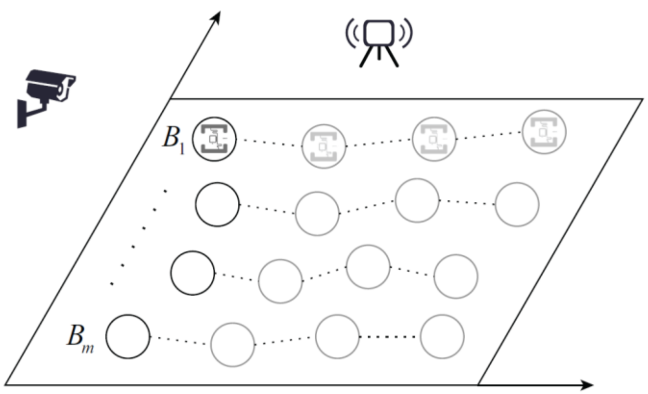
- ✓ Pros: high accuracy, low overhead, etc
- ✓ Cons: unable to identify or distinguish specific targets

# Object Identification and Tracking

## State-of-the-art work

### TagVision [1]

✓ A hybrid RFID and CV system for accurate tracking of tagged object




✓ Pros: high tracking accuracy

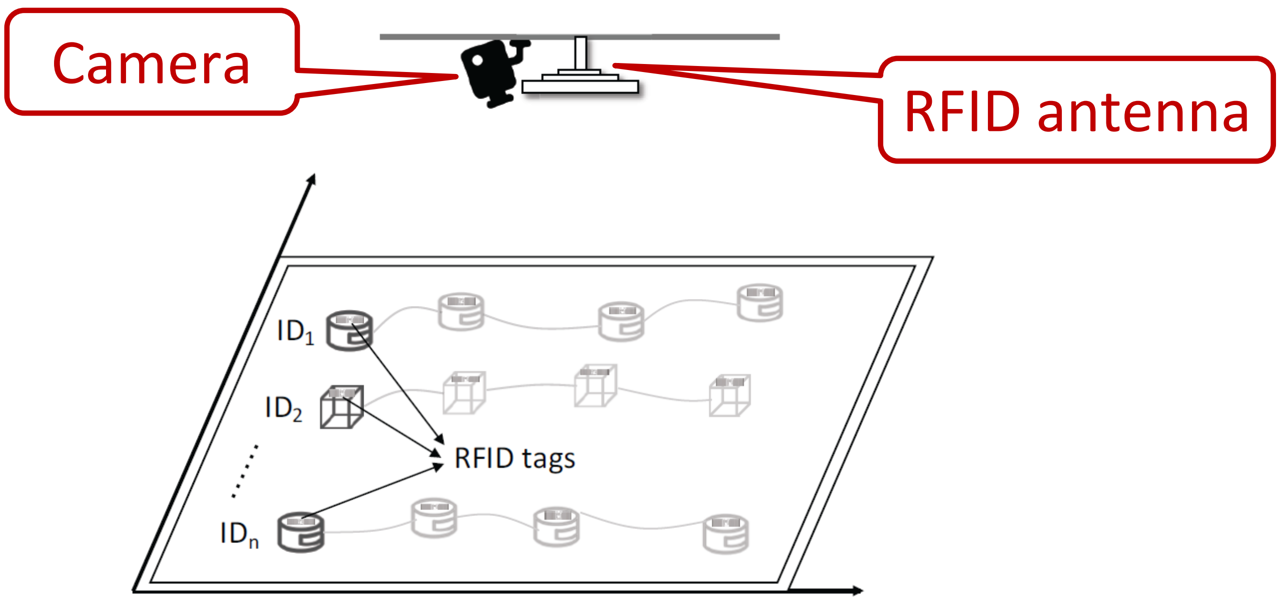
✓ Limitations:

a) only focuses on the identifying and tracking of a single target
b) requires to calibrate the camera in advance
c) the calibration effort is not one-time-only

[1] *C. Duan, X. Rao, L. Yang and Y. Liu, "Fusing RFID and computer vision for fine-grained object tracking," in Proceedings of IEEE INFOCOM, Atlanta, GA, 2017, pp. 1-9.*

# Overview of Our System

Tagview




A calibration-free, lightweight, and fine-grained identifying and tracking system for multiple objects. No repetitive camera calibration efforts are needed.

# Overview of Our System

## Tagview

Steps:

- ✓ Image-level object tracking: we detect and track moving objects in image-level using state-of-the-art deep learning-based algorithms.
- ✓ Analyzing tag-object relationship: we come up with a linear model to measure the consistency between a given pair of tag and object.
- ✓ Real-world target identification: we realize identification of targets by figuring out an optimal mapping between objects and tags.

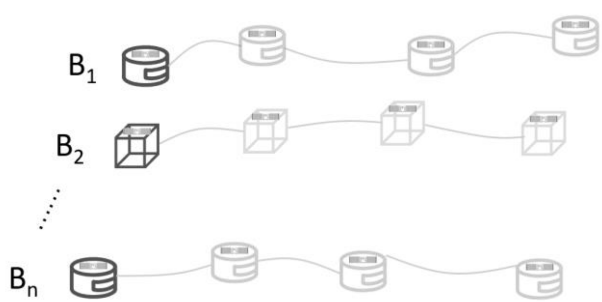
# Technical details

# Image-Level Object Tracking

Multiple object detector[1]: single shot detector (SSD) approach

Continuous frame tracker[2]: simple online and realtime tracker (SORT) method

Trajectories:



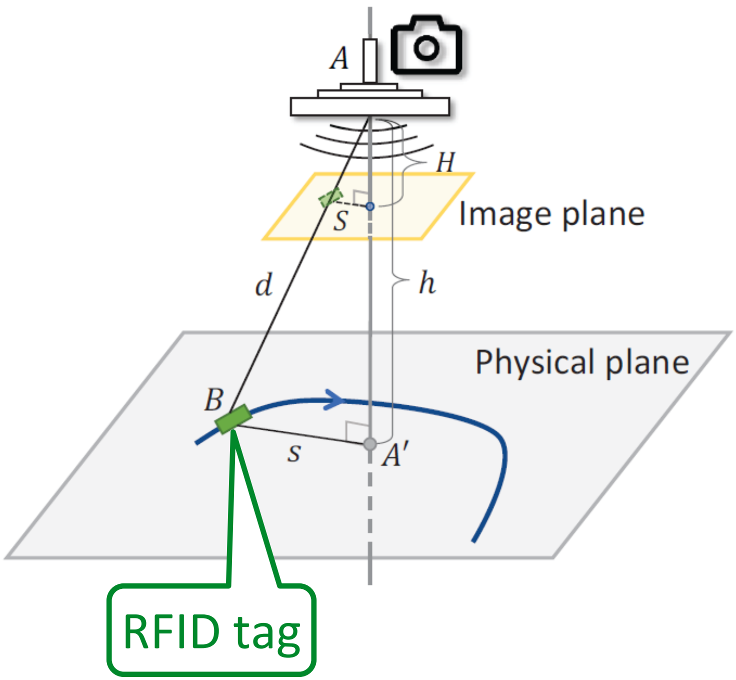


[1] *W. Liu, D. Anguelov, D. Erhan, C. Szegedy, S. Reed, C.-Y. Fu, and A. C. Berg, "SSD: Single shot multibox detector," in Proceedings of ECCV, 2016, pp. 21–37.*

*[2] A. Bewley, Z. Ge, L. Ott, F. Ramos, and B. Upcroft, "Simple online and realtime tracking," in Proceedings of ICIP, 2016, pp. 3464–3468.*

# Analyzing Tag-Object Relationship

## Modeling backscatter signal




Phase of tag

$$\theta(t) = \left(\frac{2\pi}{\lambda} \times 2d(t) + c\right) \bmod 2\pi$$
$$= \left(\frac{4\pi}{\lambda}\sqrt{h^2 + s^2(t)} + c\right) \bmod 2\pi$$

and $$\frac{s(t)}{S(t)} = \frac{h}{H}$$

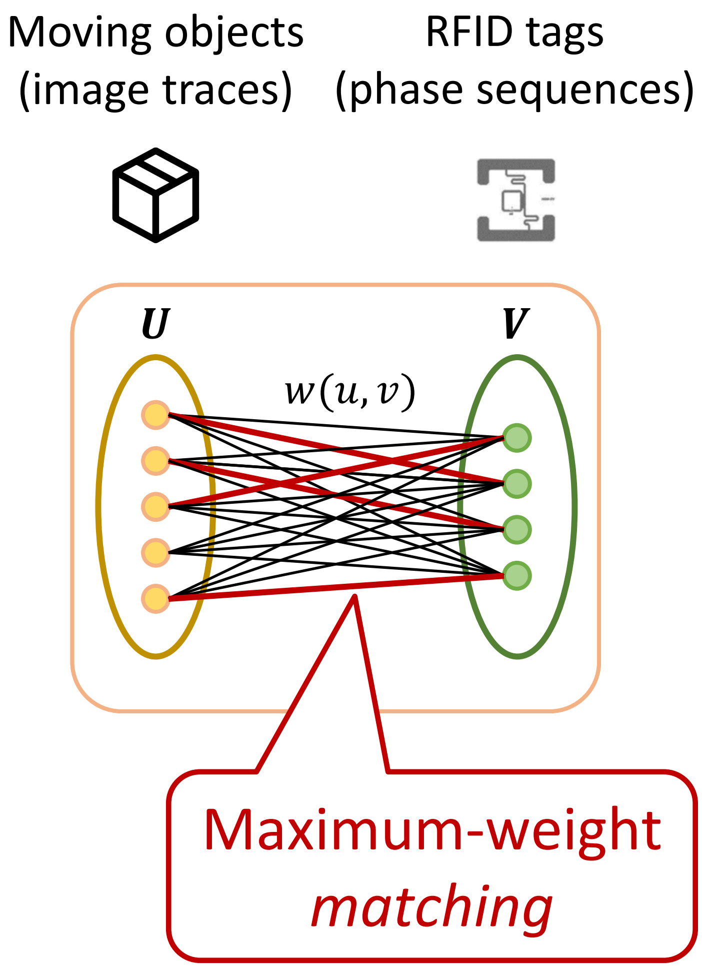
$$\Rightarrow \quad \theta(t) = \frac{4\pi h}{\lambda}\sqrt{1 + \frac{S^2(t)}{H^2}} + c.$$

$\gamma$

$\theta$ is linearly dependent on parameter $\gamma$.
$\gamma$ can be computed with the image-level trace.

# Real-World Target Identification

## Matching in bipartite graph




- ✓ The weight $w(u, v)$ denotes the fitness of a pair of object and tag.

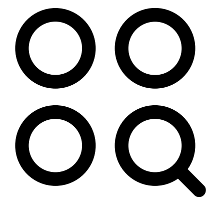
$$\theta(t) = a \times \gamma(t) + b$$

- ✓ Given $\theta$ and $\gamma$, we utilize linear regression to estimate the coefficients $a$ and $b$.
- ✓ $w$ is defined as the R-squared of the linear regression.

$$R^2 = 1 - \frac{\sum_i (\theta[t_i] - (a\gamma_i + b))^2}{\sum_i \left(\theta[t_i] - \bar{\theta}\right)^2}$$

# Practical Challenges

Imperfect RF measurements



Inevitable ambiguity in tags' phase

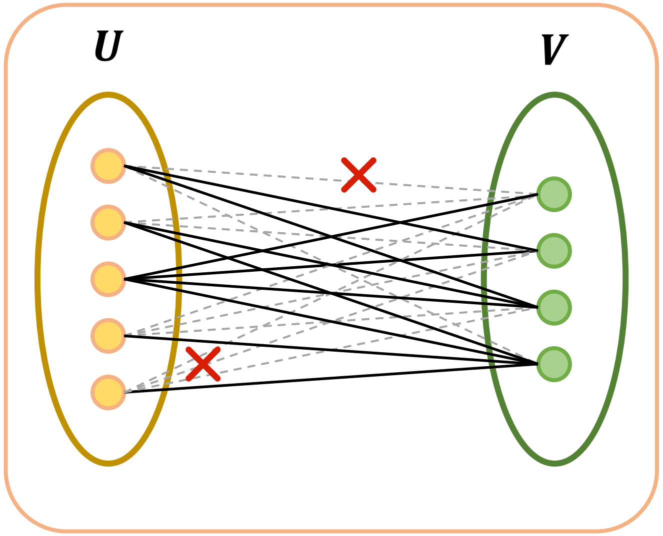
Directly utilizing the maximum matching may not conform to the ground truth.

# Real-World Target Identification

## Pruning invalid edges in the graph

### Observation

- All correctly matched pairs of objects and tags should maintain the same coefficient $a = \frac{4\pi h}{\lambda}$ in the linear model.



# Real-World Target Identification

## Incorporating tag's RSSI

- ✓ Compute an *agreement* value for any two edges (object-tag pairs) in the graph
- ✓ An agreement matrix $\boldsymbol{Q}$ can be established

$$\boldsymbol{Q}$$

$$\begin{bmatrix} 1 & 0.4 & \cdots & 0.8 \\ 0.6 & 1 & \cdots & 0.5 \\ \vdots & \vdots & \ddots & \vdots \\ 0.3 & 0.1 & \cdots & 1 \end{bmatrix}$$

# Real-World Target Identification

## Selecting edges (object-tag pairs)

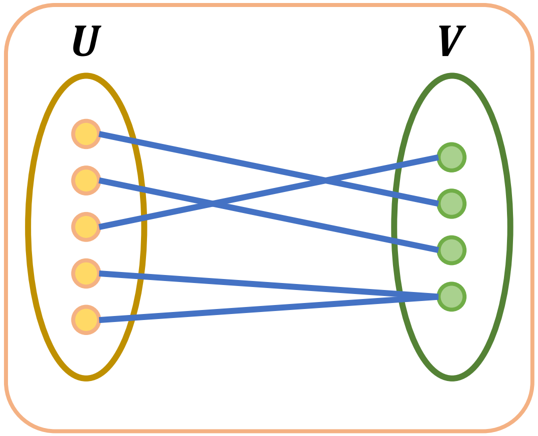
- ✓ $\boldsymbol{X}$ denotes the selection result
- ✓ Formalized as the optimization problem:

Agreement matrix

Weight matrix

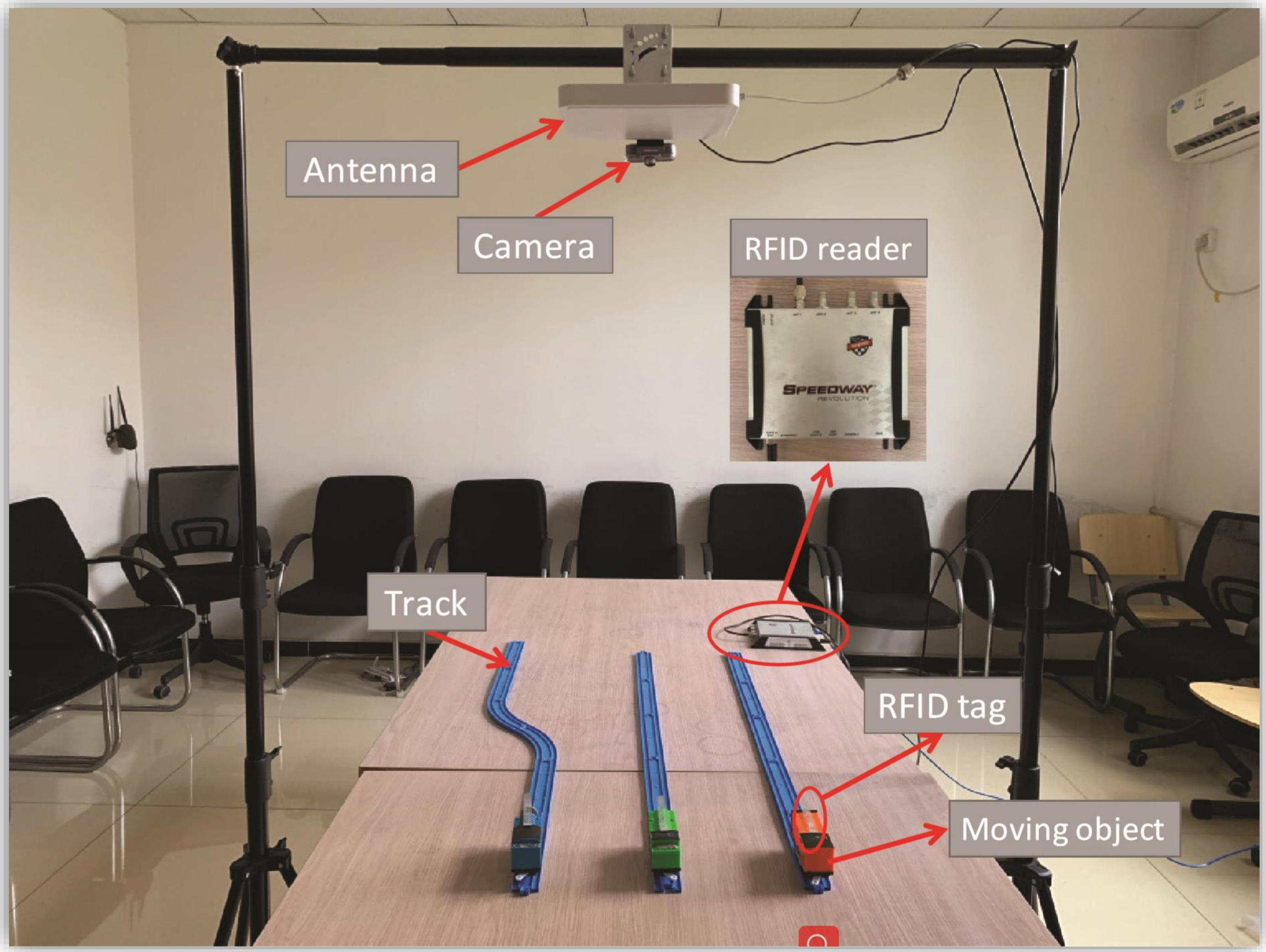
$$\max_{\mathbf{X}} \mu \mathbf{X}^{\mathrm{T}} \mathbf{Q} \mathbf{X} + \mathbf{W} \mathbf{X},$$

$$\mathbf{P}\mathbf{X} \leq \mathbf{1}, \mathbf{X}_i \in \{0, 1\}$$

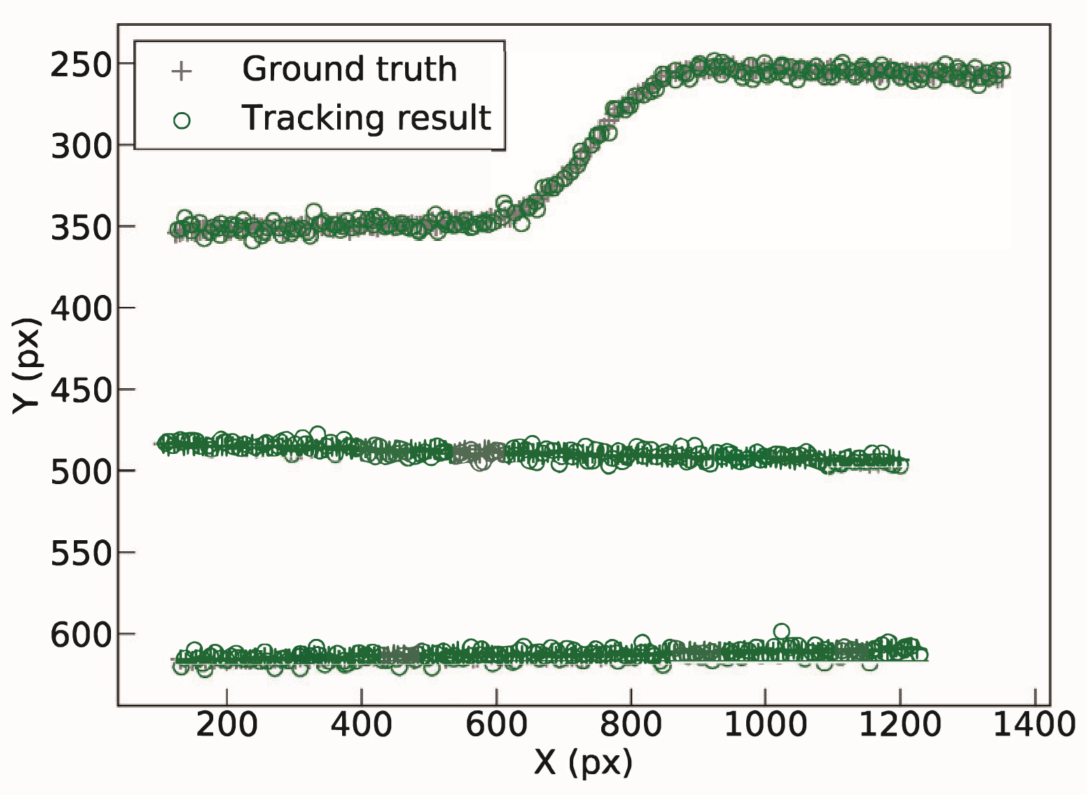


# Implementation & Evaluation

# Experimental Setup

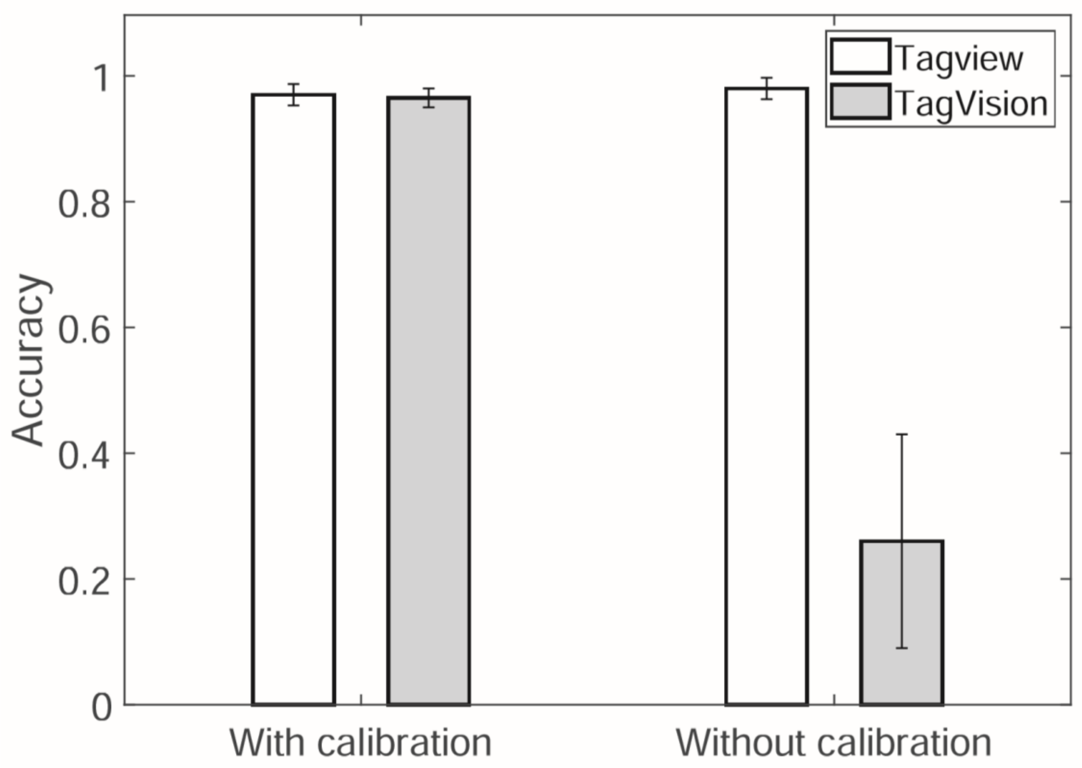


# Accuracy of Multi-Object Tracking



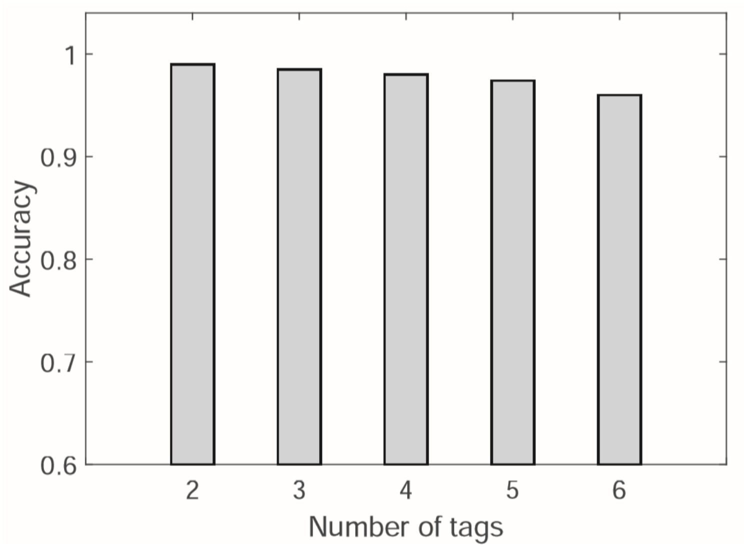

The mean error distance is 4.82 pixels (corresponding to a 5.36mm physical distance).

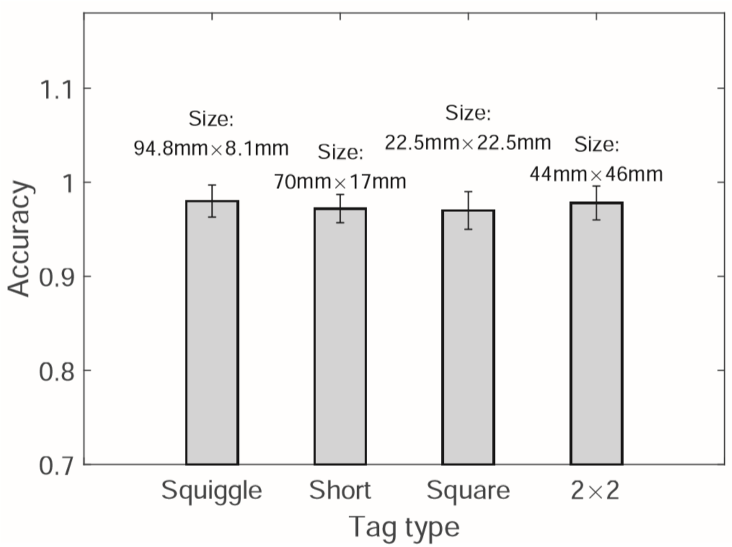
# Accuracy of Target Identification




Tagview achieves 0.98 identification accuracy on average without camera calibration.

# Robustness in Various Settings




Generally speaking, our method works well with multiple objects and different models of tags.

# Conclusion

- ✓ We present a pervasive identification and tracking approach for multiple objects with the fusion of RFID and CV techniques.
- ✓ We design a novel identification schema that works with only image-level trajectory information.
- ✓ Tagview can achieve high target recognition and tracking accuracy.

Thanks

Q&A