Sph2Pob: Boosting Object Detection on Spherical Images with Planar Oriented Boxes Methods

Xinyuan Liu[1,2], Hang Xu[3], Bin Chen[1,2], Qiang Zhao[1], Yike Ma[1], Chenggang Yan[3], Feng Dai[1*]

[1]Institute of Computing Technology, Chinese Academy of Sciences, Beijing, China
[2]University of Chinese Academy of Sciences, Beijing, China
[3]Hangzhou Dianzi University, Hangzhou, China

Macao, S.A.R. August 19-25, 2023.

* Corresponding authors

IJCAI/2023 MACAO

Overview

➢ Topic

- **Task:** detect (locate+classfy) objects on panoramic / spherical images.
- **Application:** environment perception for robotics and automatic driving.
- **Focus point:** IoU calculation and loss design for spherical bounding boxes.

➢ Challenges

- It's hard to balance differnetiablity, accuracy and speed in spherical IoU calculation.
- It's hard to design better spherical loss functions beyond naive L1-Loss.

➢ Contributions

- convert spherical boxes into planar oriented boxes in pairs, named as Sph2Pob.
- implement a differentiable, fast, accurate spherical IoU based on Sph2Pob.
- implement flexible and extensible spherical loss functions based on Sph2Pob.

Spherical/Panoramic Image

IJCAI/2023 MACAO

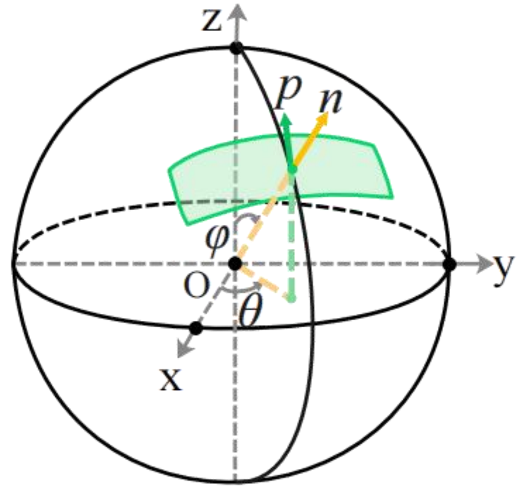
- Spherical/Panoramic image is a natural extend of comon planar image.
- It has the whole 360° view with richer information and higher practice value.
- Spherical image has two display mode, i.e., sphere and ERP.

Sphere

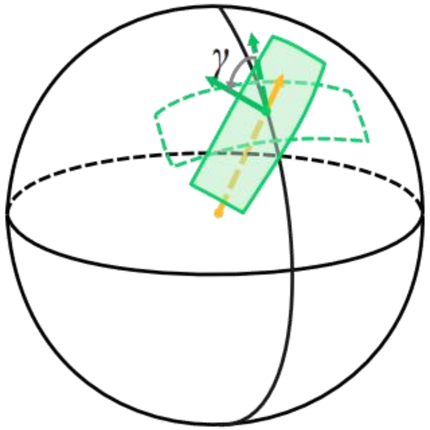
Equal Rectangular Projection (ERP)

Spherical Bounding Box

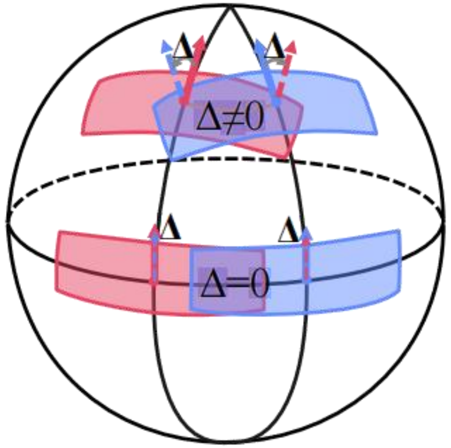
- Spherical bounding box is defined as $(\theta, \phi, \alpha, \beta, \gamma)$.
- $p(\theta, \phi)$ is the tangent point of the sphere and rectangular tangent plane. *(similar to center)*
- α and β are the horizontal and vertical fields of view of the spherical bounding box. *(similar to width/height)*



- γ is rotated angle around center-axis $n(\theta, \phi)$.
- Apart from γ , another rotated angle Δ coupled with box-pair exists on sphere. **[our insight]**
- we call γ as *external angle*, while Δ as *internal angle*.



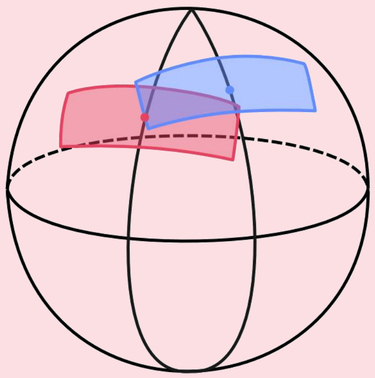
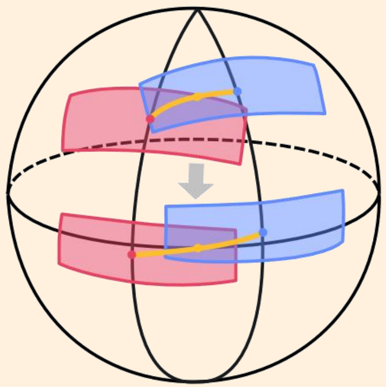
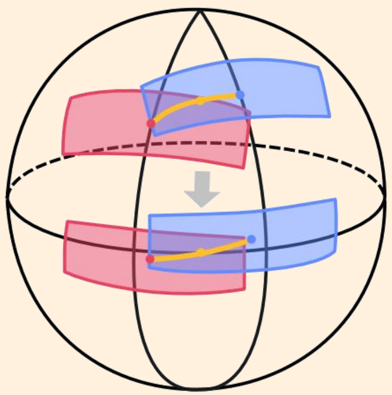
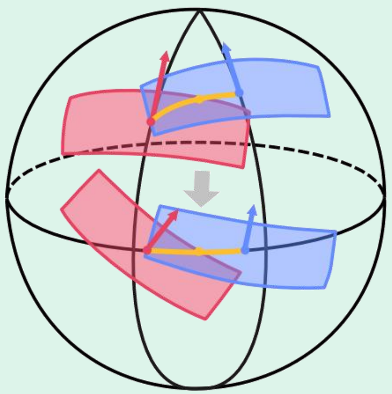
external angle



internal angle

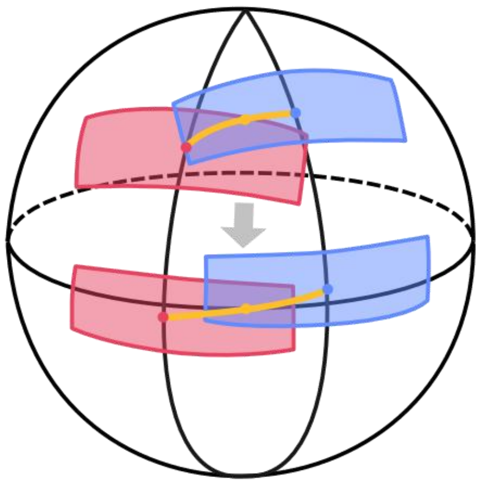
IJCAI/2023 MACAO

Overlap(IoU) Calculation

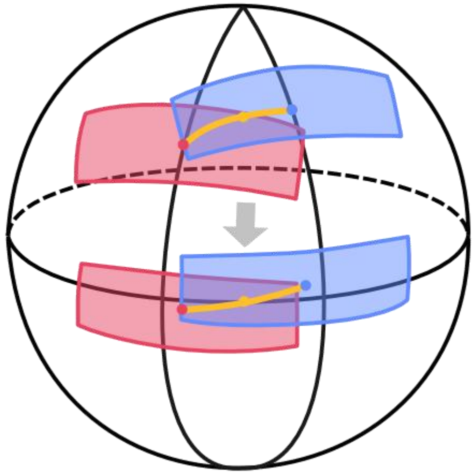
	Exact Method	Approximate Method		Approximate Method
Method	 Unbiased-IoU	 Sph-IoU	 FoV-IoU	 Sph2Pob-IoU(Our)
differentiablity	☆☆☆☆☆	★★★★★	★★★★★	★★★★★
speed	★☆☆☆☆	★★★★★	★★★★★	★★★★☆
accuracy	★★★★★	★☆☆☆☆	★★☆☆☆	★★★★☆

Overlap(IoU) Calculation

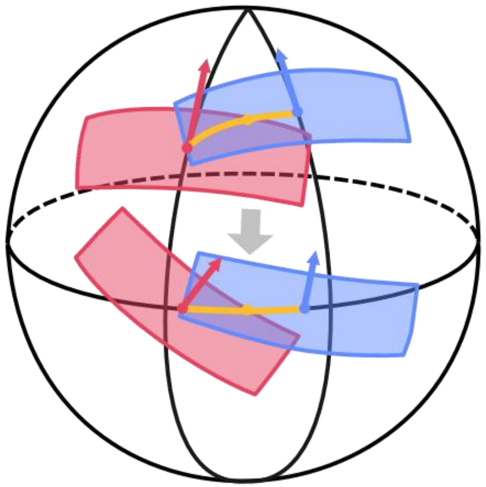
IJCAI/2023 MACAO



Sph-IoU



FoV-IoU



Sph2Pob-IoU(Our)

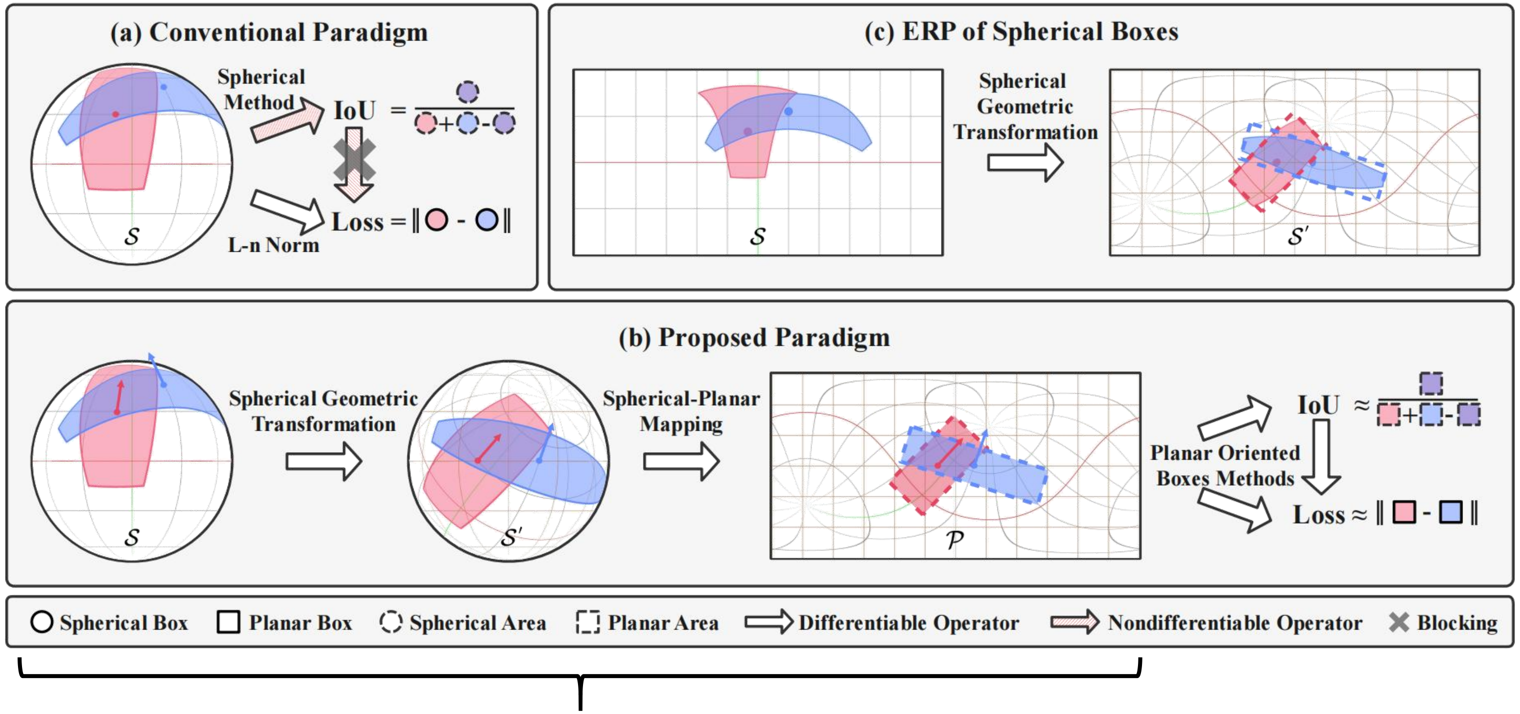
- ✓ Try to move boxes to the equator, which is the line with no distortion on ERP-images.
- × Fail to ensure the boxes after moving on the equator.
- × Ignore the internal angle, so relative poses change.

- ✓ Continue to move boxes to the equator.
- ✓ Ensure the boxes on the equator.
- ✓ Preserve the internal angle and relative pose.

Sph2Pob

IJCAI/2023 MACAO

- **S**pherical **G**eometric **T**ransformation can move boxes without any infoloss.
- **S**pherical-**P**lanar **M**apping is also used to calculate more general loss beyond IoU.



★Sph2Pob-IoU★
differentiable, precise, quick

★Sph2Pob-Loss★
metric-consistent, choice-rich

★Sph2Pob★ : well approximated box transform

7

IJCAI/2023 MACAO

Mathematical Details

1. Compute position and pose.

$$\boldsymbol{n} = \boldsymbol{n}(\theta, \phi) = [nx, ny, nz]^\top$$
$$= [\sin(\phi)\cos(\theta), \sin(\phi)\sin(\theta), \cos(\phi)]^\top$$
$$\boldsymbol{p} = \boldsymbol{p}(\theta, \phi) = \frac{\partial \boldsymbol{n}(\theta, \phi)}{\partial \phi} = [px, py, pz]^\top$$
$$= [\cos(\phi)\cos(\theta), \cos(\phi)\sin(\theta), -\sin(\phi)]^\top$$

2. Construct spherical transformation.

$$\boldsymbol{R} = [\boldsymbol{v}_x, \boldsymbol{v}_y, \boldsymbol{v}_z]^\top = \left[\frac{\boldsymbol{n}_1+\boldsymbol{n}_2}{\|\boldsymbol{n}_1+\boldsymbol{n}_2\|}, \frac{\boldsymbol{n}_1-\boldsymbol{n}_2}{\|\boldsymbol{n}_1-\boldsymbol{n}_2\|}, \boldsymbol{v}_x \times \boldsymbol{v}_y\right]^\top$$

3. Transform position and pose.

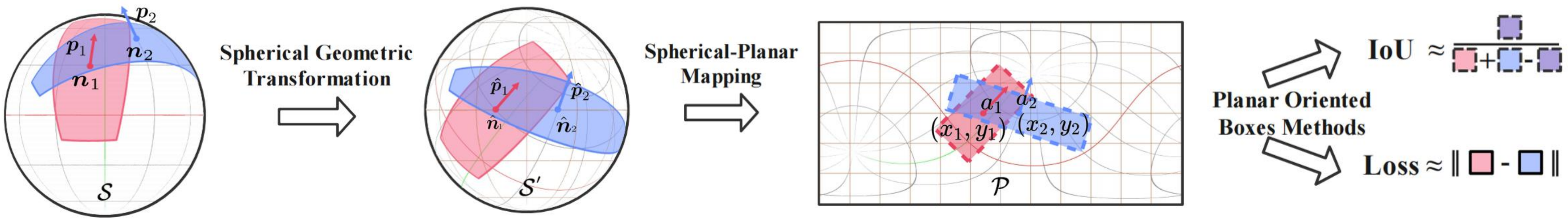
$$\hat{\boldsymbol{n}}(\hat{\theta}, \hat{\phi}) = \boldsymbol{R}\,\boldsymbol{n}(\theta, \phi) \qquad [\hat{\boldsymbol{p}}_1, \hat{\boldsymbol{p}}_2] = \boldsymbol{R}\,[\boldsymbol{p}_1, \boldsymbol{p}_2]$$

4. Compute *Internal Angle*.

$$\Delta = \Delta_1 + \Delta_2 = \arccos(\hat{\boldsymbol{p}}_1 \cdot \hat{\boldsymbol{p}}_{ref}) + \arccos(\hat{\boldsymbol{p}}_2 \cdot \hat{\boldsymbol{p}}_{ref})$$

5. Map spherical boxes to planar boxes.

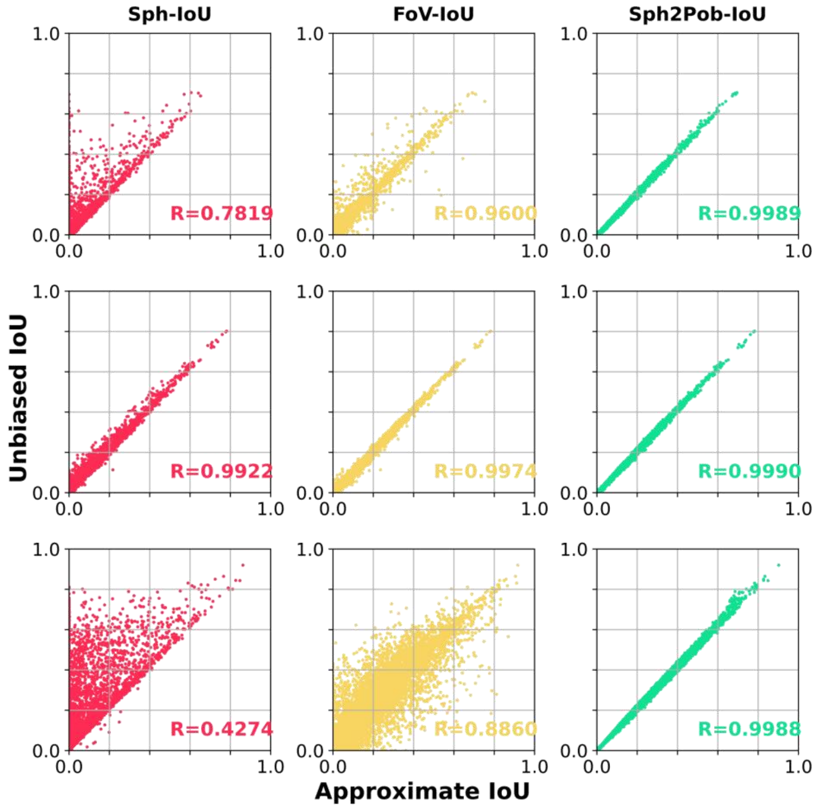
$$\mathcal{B}_i^{\mathcal{P}} = (x_i, y_i, w_i, h_i, a_i) = (\hat{\theta}_i, \hat{\phi}_i, \hat{\alpha}_i, \hat{\beta}_i, \hat{\Delta}_i)$$
$$a_i = \Delta_i + \gamma_i, i = 1, 2$$



★ IoU & Loss ★ $IoU^{\mathcal{S}}(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}) \approx IoU^{\mathcal{P}}(Sph2Pob(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}))$ $Loss^{\mathcal{S}}(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}) \approx Loss^{\mathcal{P}}(Sph2Pob(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}))$

Experiments

- Scatter of different IoU.



- Comprehensive comparison of box transform methods.

Method	Consistency			Time-cost		Detection		
	$R_{all}\uparrow$	$R_{low}\uparrow$	$R_{high}\uparrow$	$T_{cpu}\downarrow$	$T_{cuda}\downarrow$	AP↑	$AP_{50}\uparrow$	$AP_{75}\uparrow$
Sph	0.7819	0.9922	0.4274	0.0364	0.0033	10.7	24.3	7.8
Fov	0.9600	0.9974	0.8860	0.0372	0.0034	10.9	25.0	7.9
Sph2Pob	0.9989	0.9990	0.9988	2.2275	0.0096	11.5	25.7	8.2
Unbiased	1.0000	1.0000	1.0000	46.4417	-	-	-	-

- Ablation studies about edge & angle calculation.

Edge	Error↓(mean±std)	R↑
arc	0.0016±0.0042	0.9989
chord	0.0023±0.0063	0.9974
tangent	0.0086±0.0192	0.9681

Angle	Error↓(mean±std)	R↑
original	0.0025±0.0086	0.9946
equator	0.0016±0.0042	0.9989
project	0.0017±0.0043	0.9987

Evaluations

- Evaluation on different Loss.

Loss	360-Indoor AP↑	360-Indoor AP_{50} ↑	360-Indoor AP_{75} ↑	PANDORA AP↑	PANDORA AP_{50} ↑	PANDORA AP_{75} ↑
L1	10.2	23.0	7.8	10.3	24.3	6.6
L1†	9.9	21.9	7.7	10.1	23.7	6.8
GWD† [Yang *et al.*, 2021b]	6.8	14.5	5.6	5.9	12.3	5.0
KLD† [Yang *et al.*, 2021c]	9.5	21.5	6.8	10.3	23.5	7.1
KFIoU† [Yang *et al.*, 2022b]	8.5	19.7	6.2	9.6	23.2	5.6
IoU† [Yu *et al.*, 2016]	9.8	22.1	6.8	10.4	24.8	6.9
GIoU† [Rezatofighi *et al.*, 2019]	10.5	23.9	7.8	10.3	24.7	6.8
DIoU† [Zheng *et al.*, 2020]	11.0	24.6	8.2	10.4	24.8	7.0
CIoU† [Zheng *et al.*, 2021]	11.5	25.7	8.2	10.5	25.3	7.0

- Evaluation on different detectors.

Detector	Loss	360-Indoor AP↑	360-Indoor AP_{50} ↑	360-Indoor AP_{75} ↑	PANDORA AP↑	PANDORA AP_{50} ↑	PANDORA AP_{75} ↑
Faster R-CNN	L1	12.5	28.1	9.1	11.0	27.8	6.2
	CIoU†	12.9	29.1	9.4	11.3	28.6	7.1
SSD	L1	10.8	27.6	6.3	9.5	25.8	4.6
	CIoU†	12.0	28.7	8.0	10.5	26.9	6.0
FCOS	L1	8.8	20.2	6.7	7.7	19.7	4.4
	CIoU†	9.2	21.0	7.0	8.8	21.2	5.6

- Evaluation on different components, including Lable Assignment, Loss, NMS.

Label Assignment	Loss	NMS	360-Indoor AP↑	360-Indoor AP_{50} ↑	360-Indoor AP_{75} ↑	PANDORA AP↑	PANDORA AP_{50} ↑	PANDORA AP_{75} ↑
			9.8	22.2	7.0	10.4	23.8	6.9
✓			10.2	23.0	7.8	10.3	24.3	6.6
	✓		11.0	25.4	7.8	10.6	24.5	6.9
		✓	9.8	22.1	6.8	10.4	23.9	6.9
✓	✓		11.5	25.7	8.2	10.5	25.3	7.0
✓	✓	✓	11.6	26.1	8.4	10.6	25.7	7.1

IJCAI/2023 MACAO

Visualized Comparsions (360Indoor)

- Some easily confused bed/sofa/table-like objects are labeled as bed.
- With L1, predicted bboxes are coarse and category-wrong.

Ground Truth

L1

Visualized Comparsions (360Indoor)

- Some easily confused bed/sofa/table-like objects are labeled as bed.
- With our CIoU†, predicted bboxes are more compact even though category-wrong.

Ground Truth

(Ours) CIoU†

IJCAI/2023 MACAO

Visualized Comparsions (PANDORA)

- The cablinet is rotated with some angle, and lights are tiny.
- With L1, predicted box of the cablinet is corse with wrong angle, and lights are missing.

Ground Truth

L1

Visualized Comparsions (PANDORA)

IJCAI/2023 MACAO

- The cablinet is rotated with some angle, and lights are tiny.
- With our CIoU†, the cablinet is more tight with right angle, and lights are catched.

Ground Truth

(Ours) CIoU†

IJCAI/2023 MACAO

Thank You !

- **Paper:** Sph2Pob: Boosting Object Detection on Spherical Images with Planar Oriented Boxes Methods
- **Codes:** https://github.com/AntXinyuan/sph2pob
- **Contact:**

  - Xinyuan Liu: liuxinyuan21s@ict.ac.cn
  - Hang Xu: hxu@hdu.edu.cn
  - Feng Dai: fdai@ict.ac.cn

Homepage

Tips: All codes/posters/slides can be available on our github page.