IJCAI/2023 MACAO

Github Codes

952 | Wed 23 August 11:45-12:45 (5 / 6)

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

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❖ Introduction ❖

➢ **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, accuary 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 a flexible and extensible spherical loss functions based on Sph2Pob.

❖ Prerequisites ❖

➢ **Spherical Images**

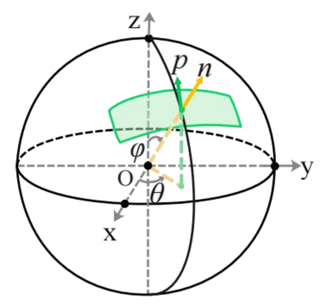
- Spherical image is a natural extend (360° view) of comon planar image.
- Spherical image has two display mode, i.e., sphere and equal rectangular projection.

Sphere

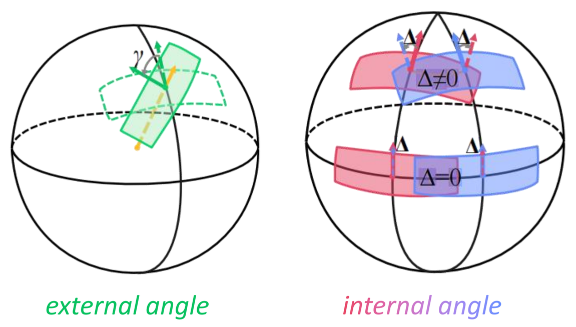
Equal Rectangular Projection (ERP)

➢ **Spherical Boxes**

- Spherical bounding box is defined as $(\theta, \phi, \alpha, \beta, \gamma)$.
- $n(\theta, \phi)$ is the tangent point of the sphere and rectangular tangent plane.
- α and β are the horizontal and vertical fields of view of the spherical bounding box.



- γ is rotated angle around center-axis $p(\theta, \phi)$.
- 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*.



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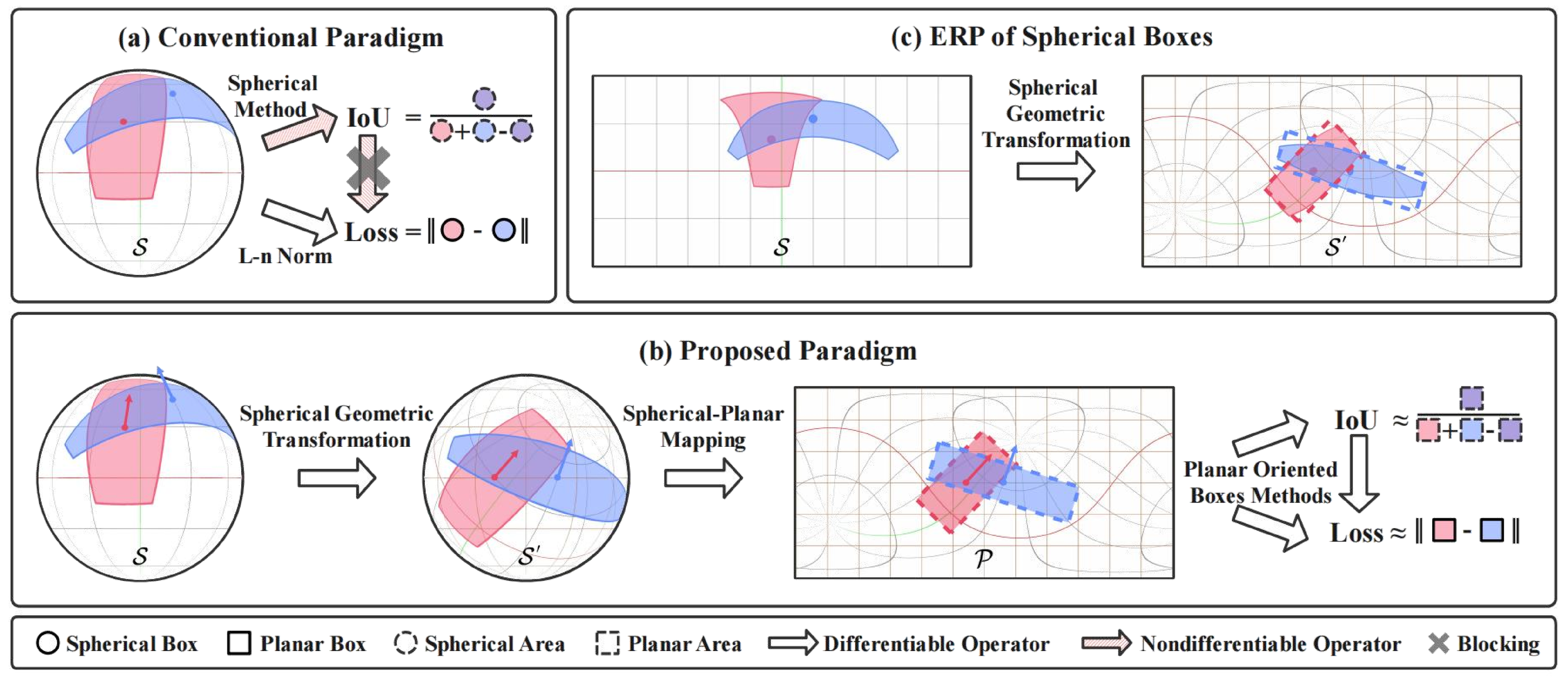
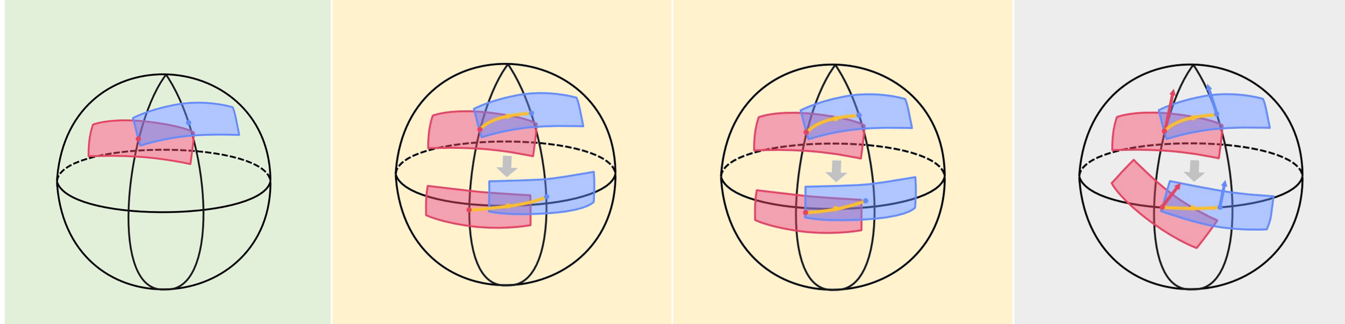
❖ Methodology ❖

➢ **Overview**



➢ **Comparsion**



	Exact Method	Approximate Method		Approximate Method
Method	Unbiased-IoU	Sph-Io2U	FoV-IoU	Sph2Pob-IoU(Our)
differentiablity	☆☆☆☆☆	★★★★★	★★★★★	★★★★★
speed	★☆☆☆☆	★★★★★	★★★★★	★★★★☆
accuracy	★★★★★	★☆☆☆☆	★★☆☆☆	★★★★☆

➢ **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.

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

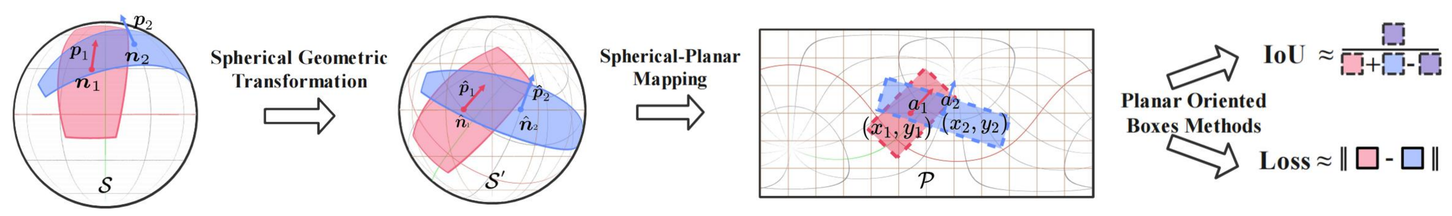
4. Compute *Internal Angle*.

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

5. Map spherical boxes to planar boxes.

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

$$a_i = \Delta_i + \gamma_i, i = 1, 2$$

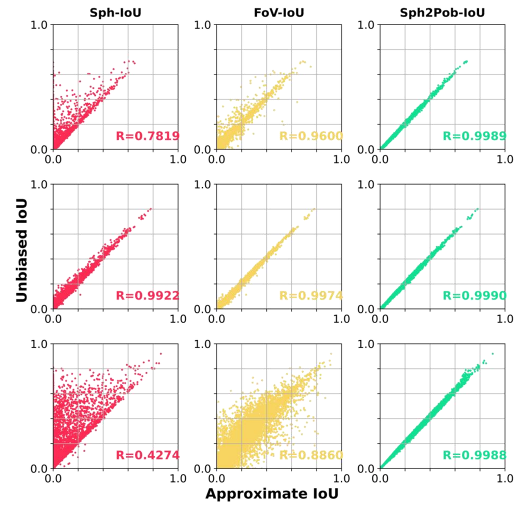


★ **IoU & Loss** ★ $IoU^{\mathcal{S}}(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}) \approx IoU^{\mathcal{P}}(Sph2Pob(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}))$ $Loss^{\mathcal{S}}(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}) \approx Loss^{\mathcal{P}}(Sph2Pob(\boldsymbol{B}_1^{\mathcal{S}},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

❖ Experiments ❖

➢ **Main Results**

- Scatter of different IoU.



- Comprehensive comparison of box transform methods.

Method	Consistency $R_{all}\uparrow$	Consistency $R_{low}\uparrow$	Consistency $R_{high}\uparrow$	Time-cost $T_{cpu}\downarrow$	Time-cost $T_{cuda}\downarrow$	Detection $AP\uparrow$	Detection $AP_{50}\uparrow$	Detection $AP_{75}\uparrow$
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↑	Angle	Error↓(mean±std)	R↑
arc	0.0016±0.0042	0.9989	original	0.0025±0.0086	0.9946
chord	0.0023±0.0063	0.9974	equator	0.0016±0.0042	0.9989
tangent	0.0086±0.0192	0.9681	project	0.0017±0.0043	0.9987

➢ **Evaluations**

- Evaluation on different Loss.

Loss	360-Indoor AP↑	360-Indoor $AP_{50}\uparrow$	360-Indoor $AP_{75}\uparrow$	PANDORA AP↑	PANDORA $AP_{50}\uparrow$	PANDORA $AP_{75}\uparrow$
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 $AP_{50}\uparrow$	360-Indoor $AP_{75}\uparrow$	PANDORA AP↑	PANDORA $AP_{50}\uparrow$	PANDORA $AP_{75}\uparrow$
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

❖ Visualization ❖