基于 RGB-D 图像的三维物体识别算法的研究与实现

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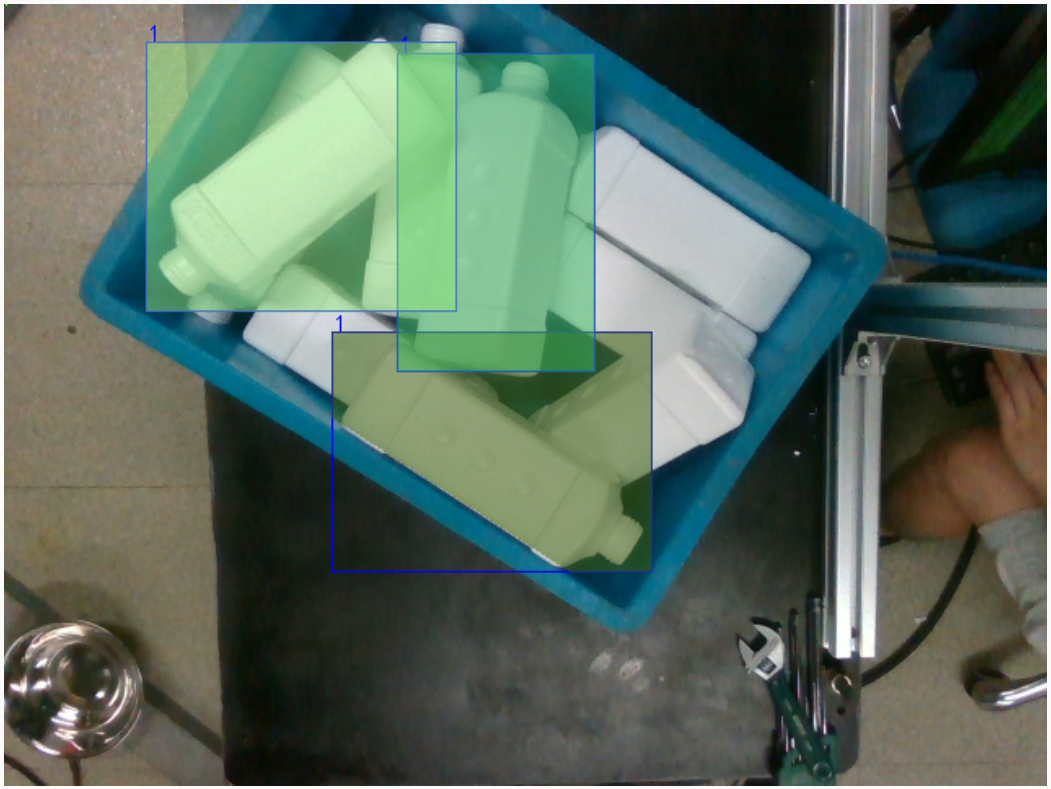
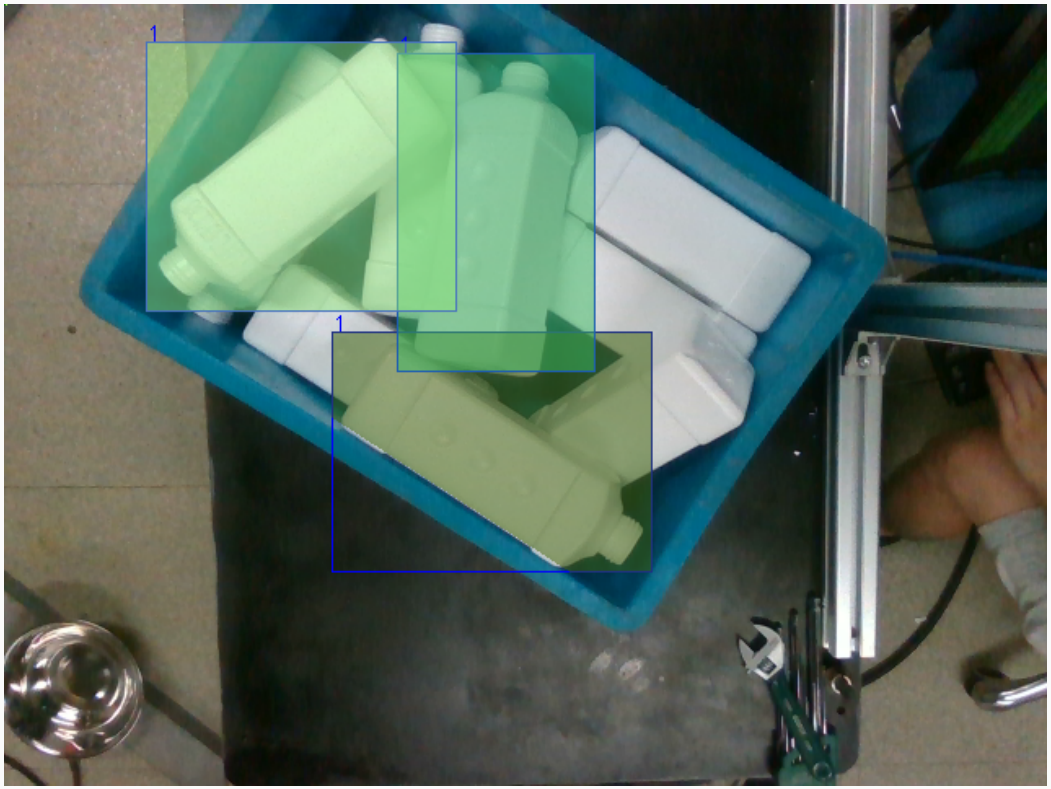
Problem

2D Detection

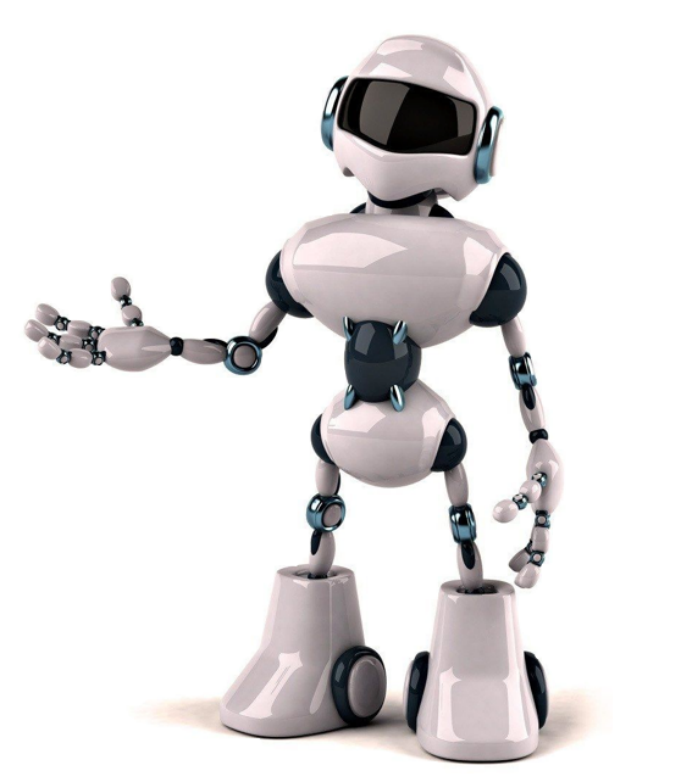


Problem

2D Detection



Where to pick?



Problem

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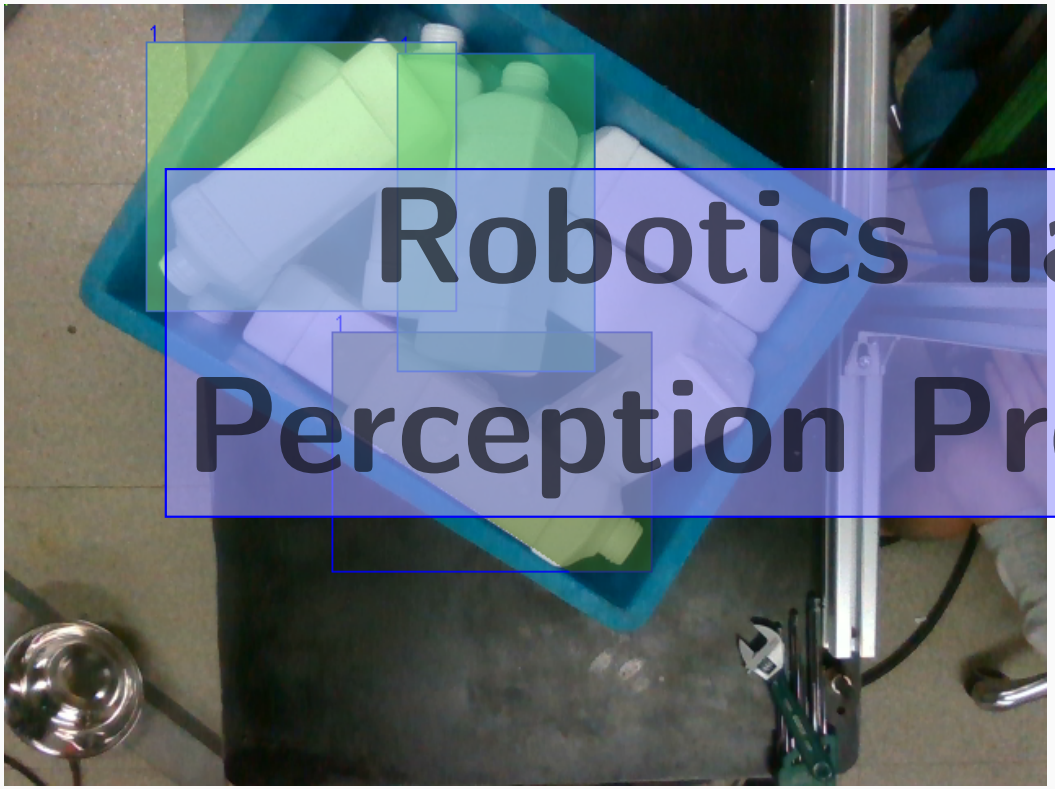

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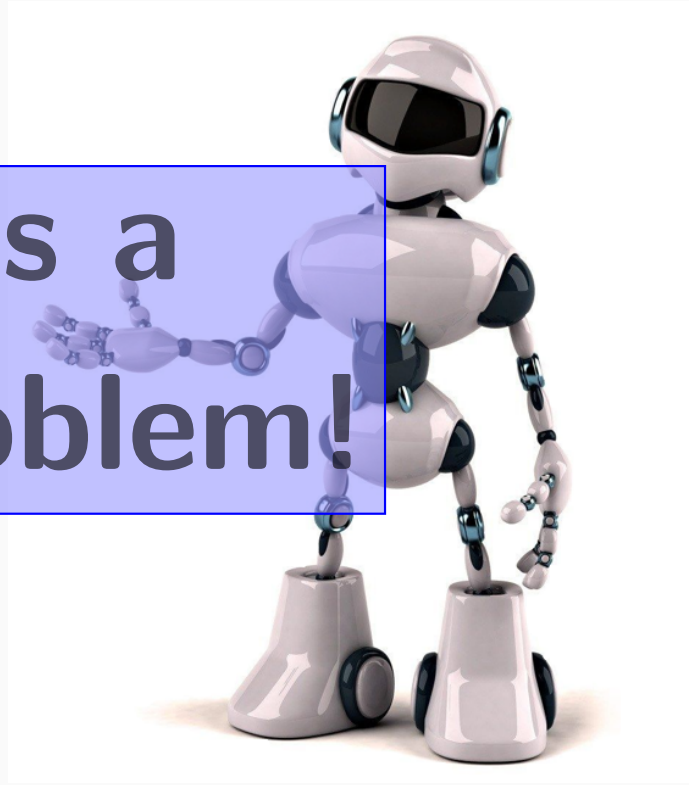
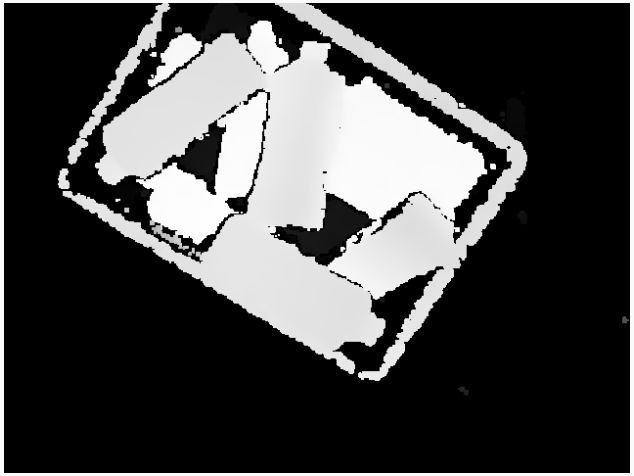


Robotics has a Perception Problem!

3D Detection

3D Detection

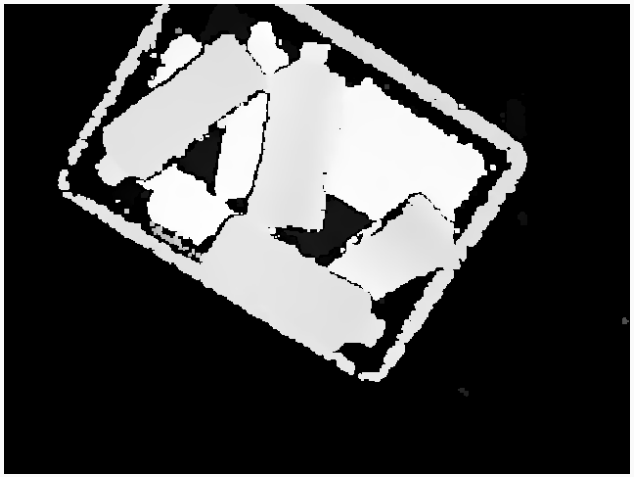
RGB Image



Depth Map

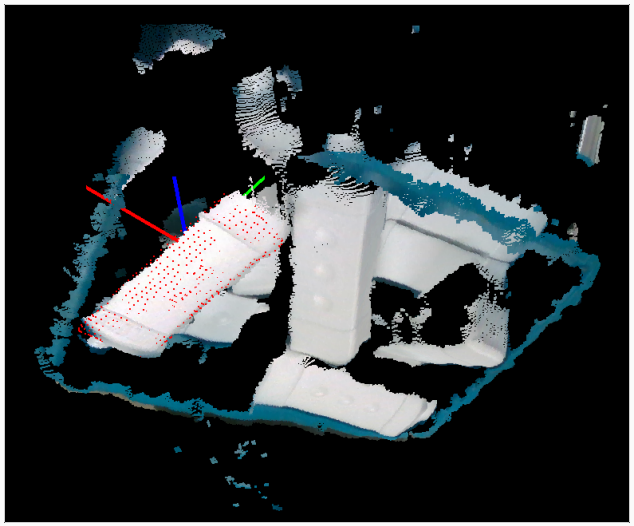
3D Detection

RGB Image



Depth Map

3D Detection Results

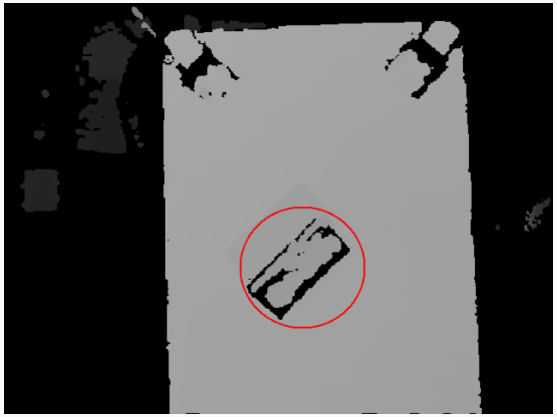


Dual RGB-D Camera

Problem & Key

Problem & Key

Problem: SR300 相机对反光物体在某些角度下深度信息有严重的缺失



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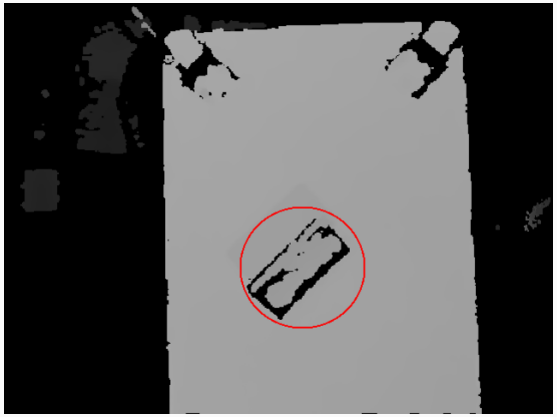
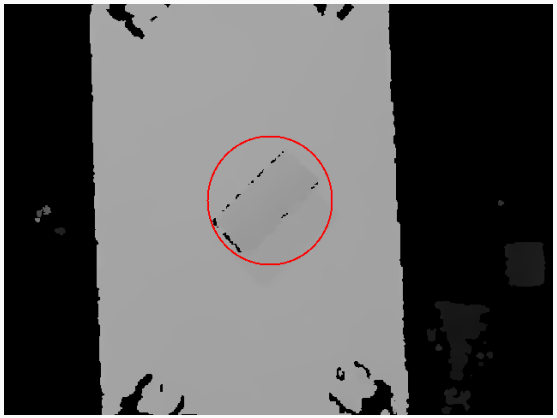


Key: 改变相机的拍摄角度



Structure of Dual RGB-D Camera

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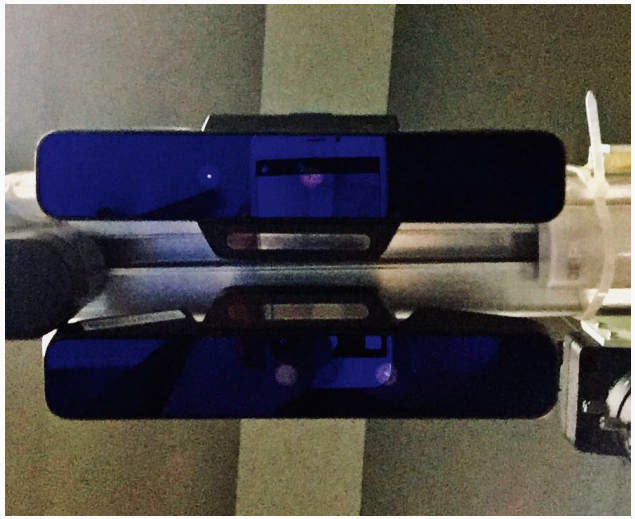
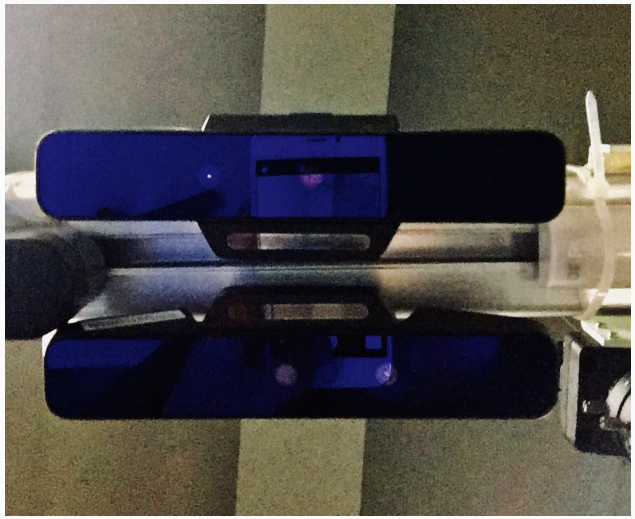


对偶 RGB-D 相机物理结构

Structure of Dual RGB-D Camera



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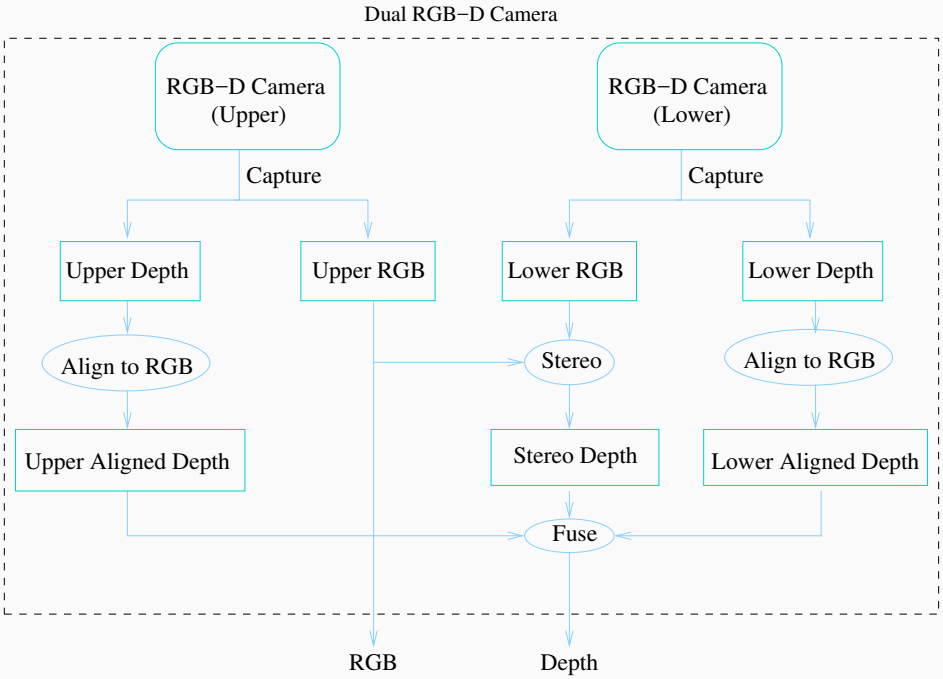
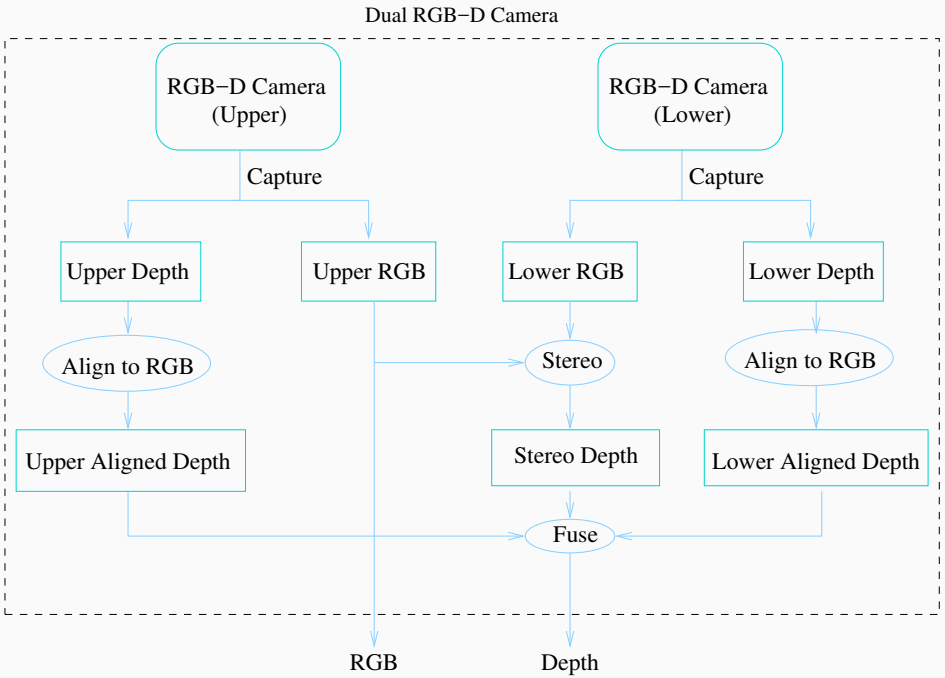


对偶 RGB-D 相机内部原理图

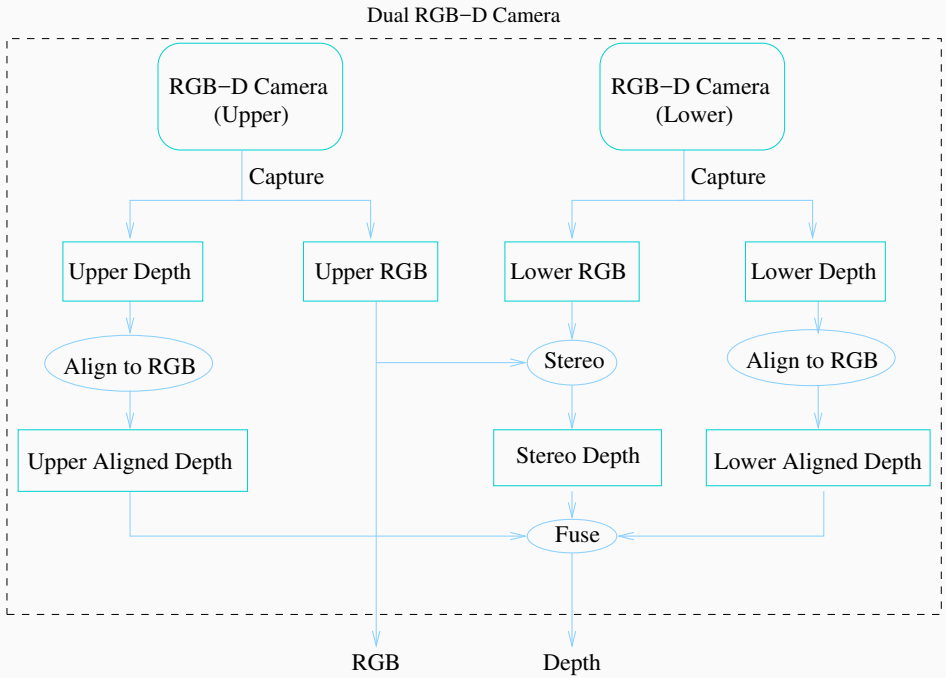
Implementation

Implementation



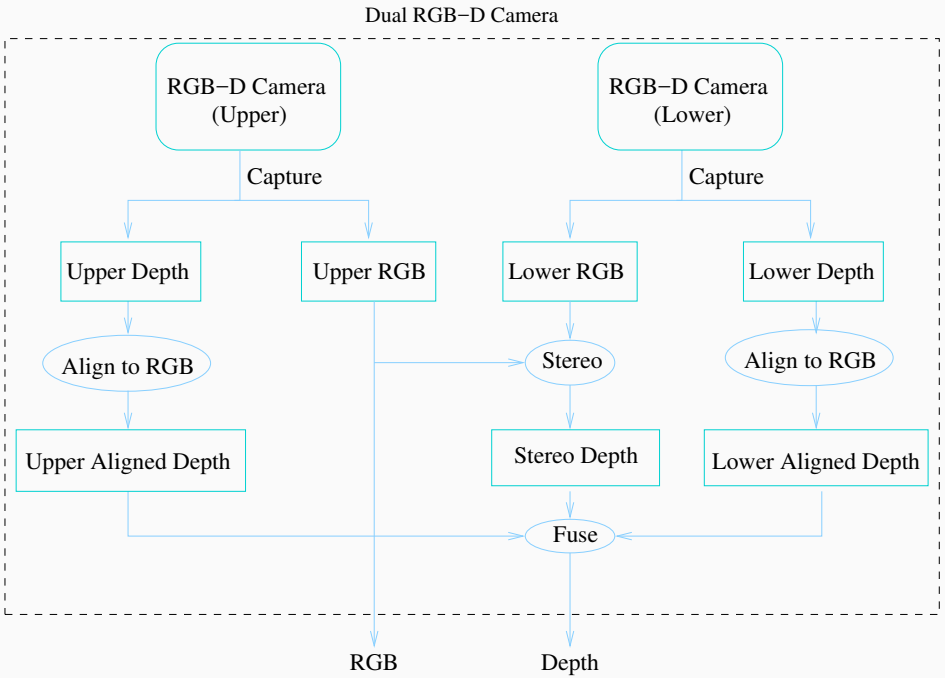
Implementation

- 将深度图与彩色图对齐



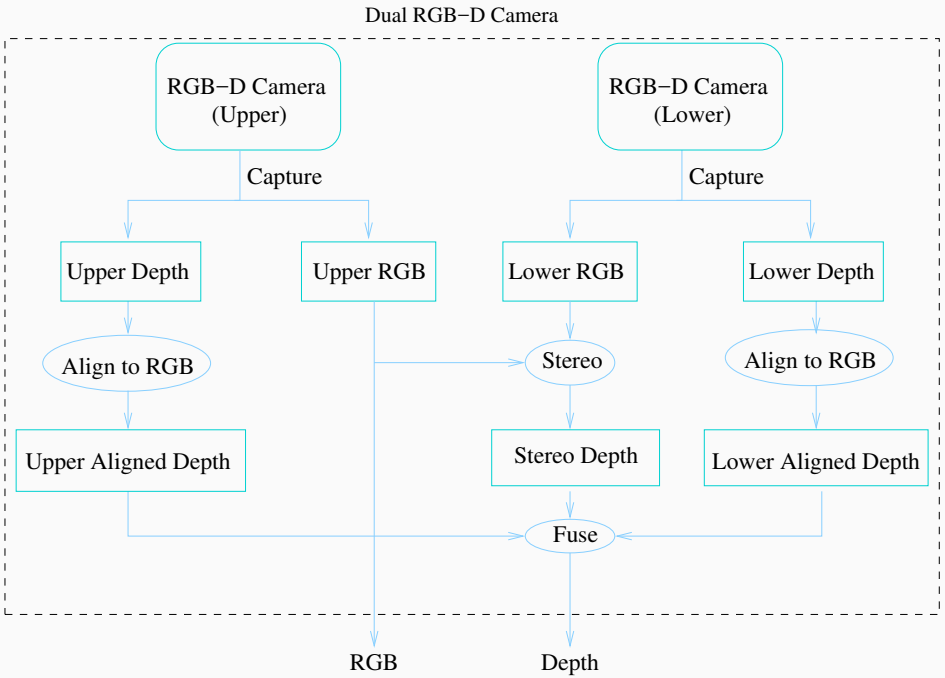
Implementation

- 将深度图与彩色图对齐
- 通过双目匹配算法 (ELAS) 形成一张新的深度图



Implementation

- 将深度图与彩色图对齐
- 通过双目匹配算法 (ELAS) 形成一张新的深度图
- 融合三张深度图



Experiment & Results

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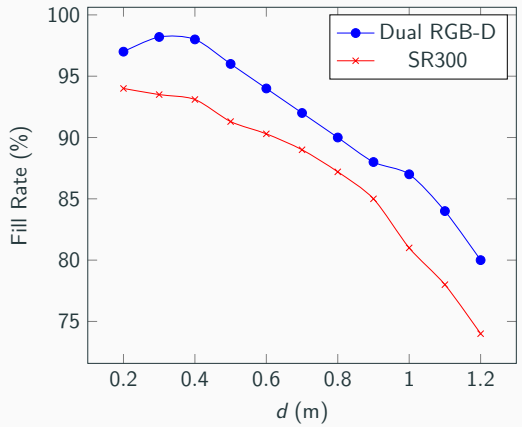
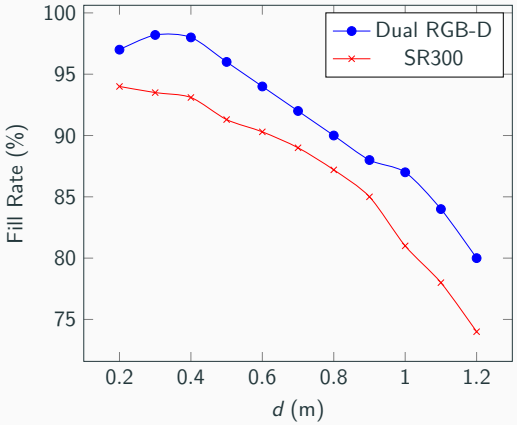
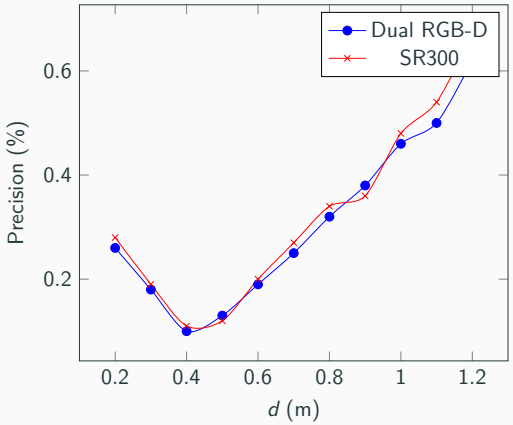


$$\frac{M'}{M} \times 100\%$$

Experiment & Results

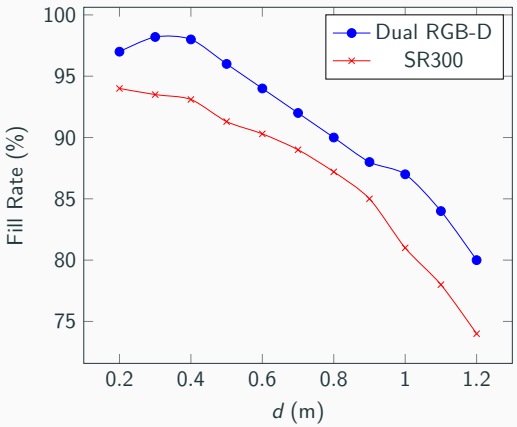




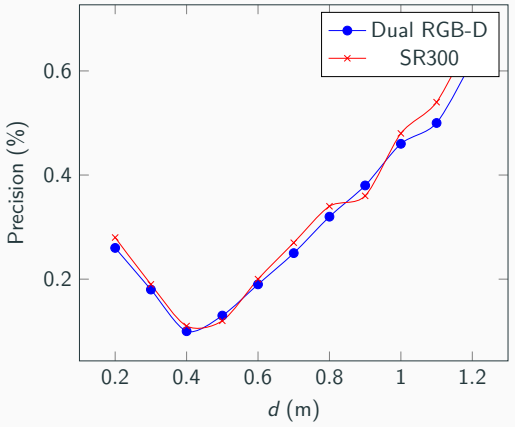
$$\frac{M'}{M} \times 100\%$$

$$\frac{|\hat{d}-d|}{d} \times 100\%$$

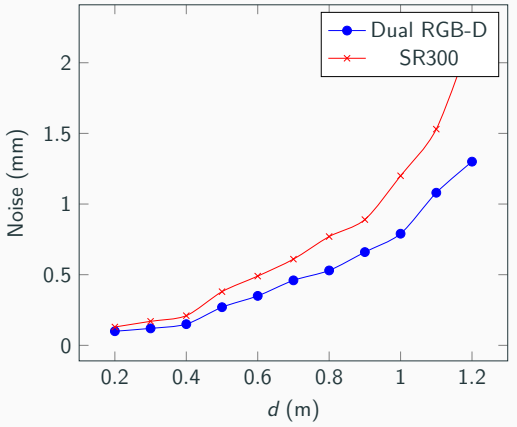
Experiment & Results



$$\frac{M'}{M} \times 100\%$$



$$\frac{|\hat{d}-d|}{d} \times 100\%$$

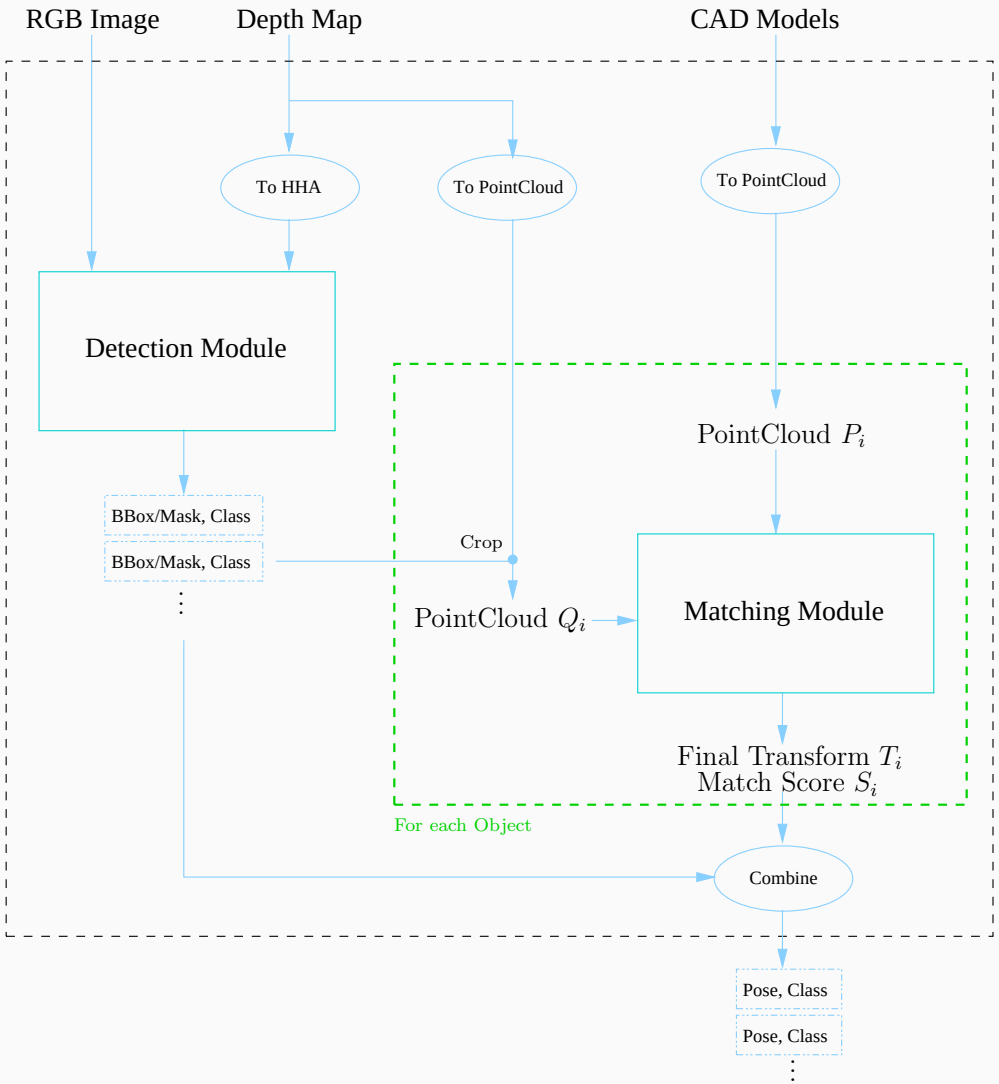


$$\sqrt{\frac{1}{N}\sum_{i=1}^{N}\delta_i^2}$$

3D-MRAI Algorithm

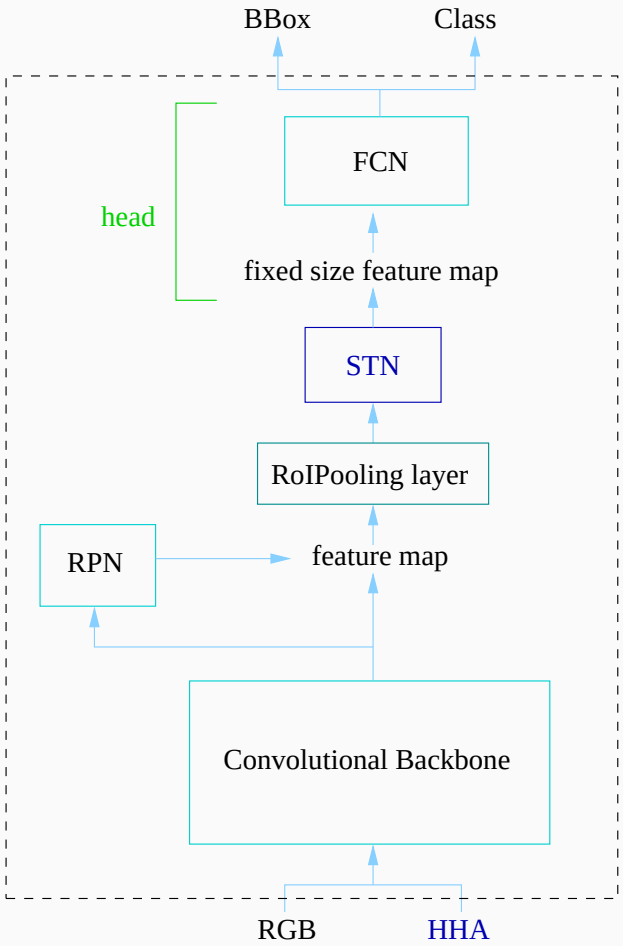
3D-MRAI

3D-MRAI (3D Mask R-CNN with Angle-fixed-4PCS and ICP)



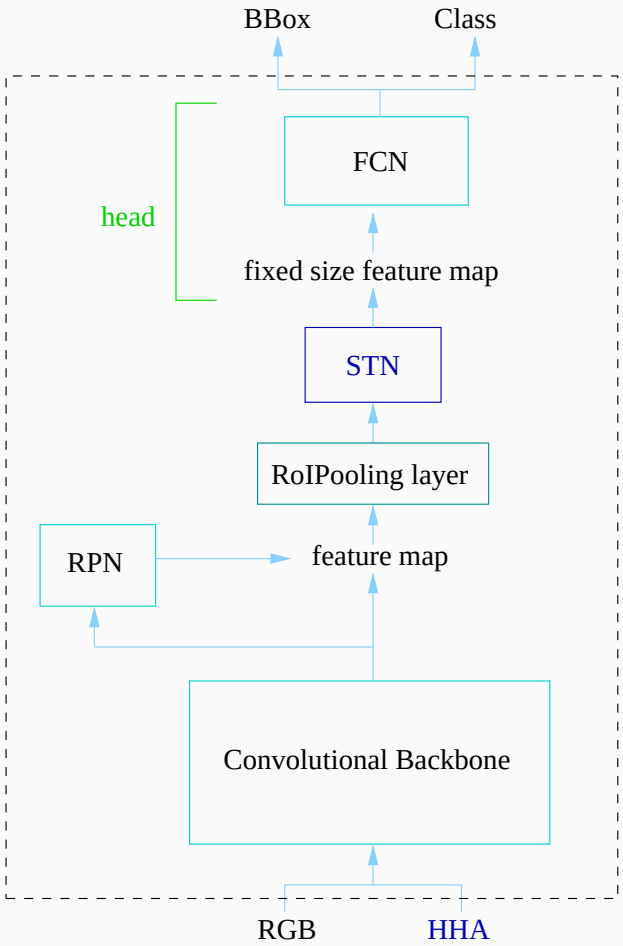
Detection Module

Detection Module

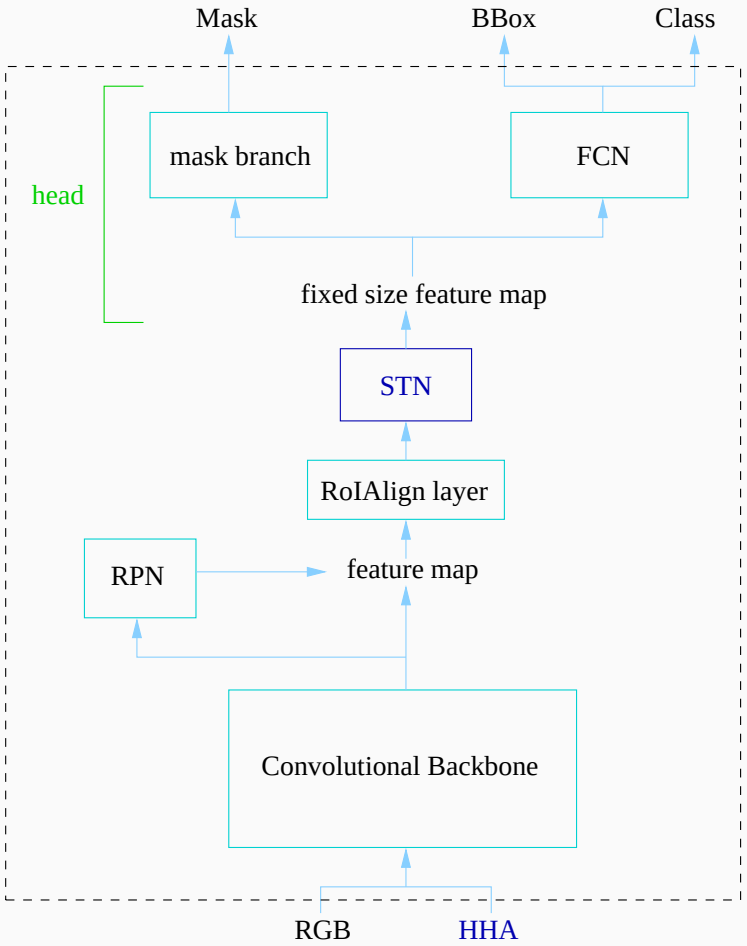


Based on Faster R-CNN

Detection Module



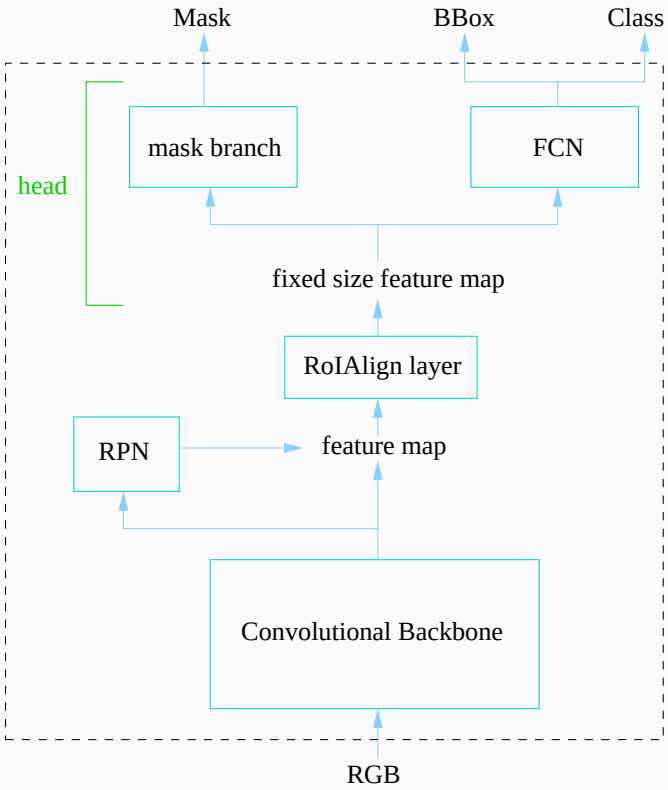
Based on Faster R-CNN



Based on Mask R-CNN

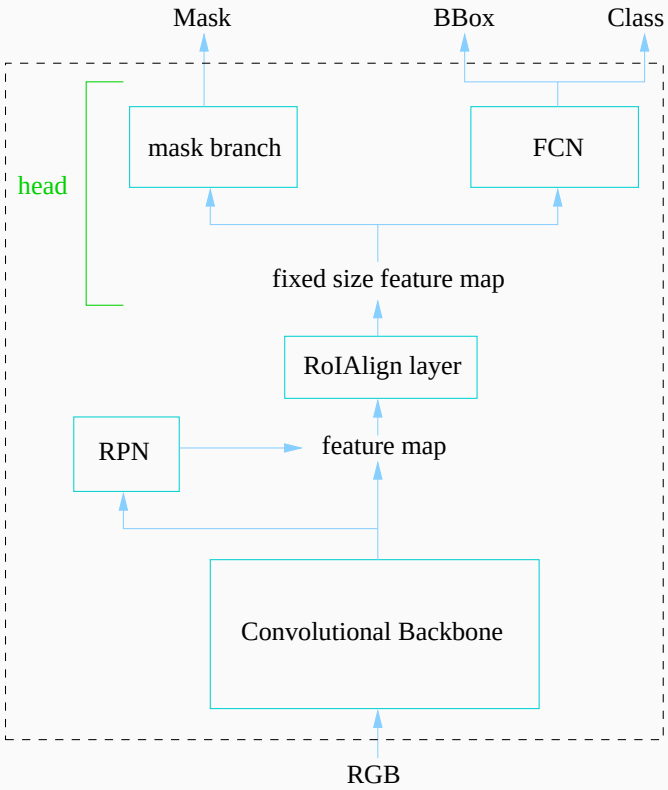
Mask R-CNN Module

Mask R-CNN Module



Original Mask R-CNN

Mask R-CNN Module



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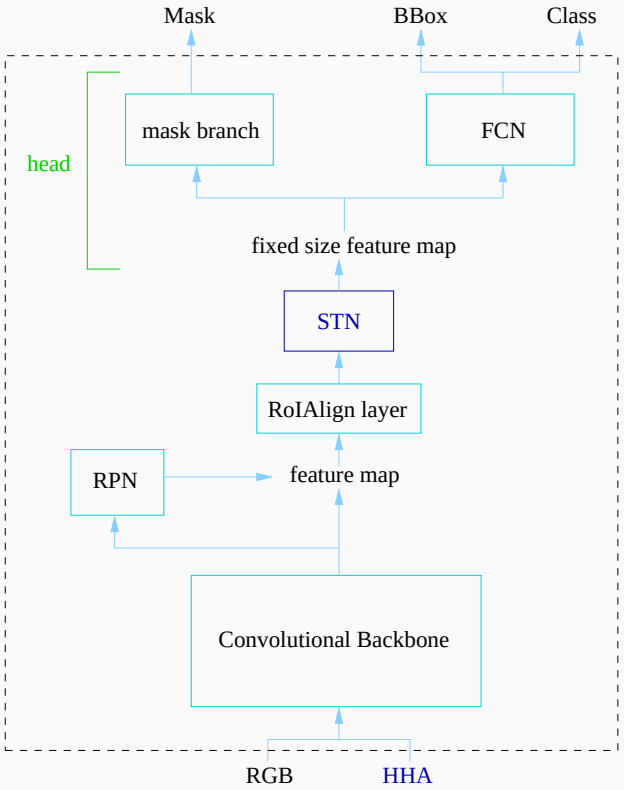
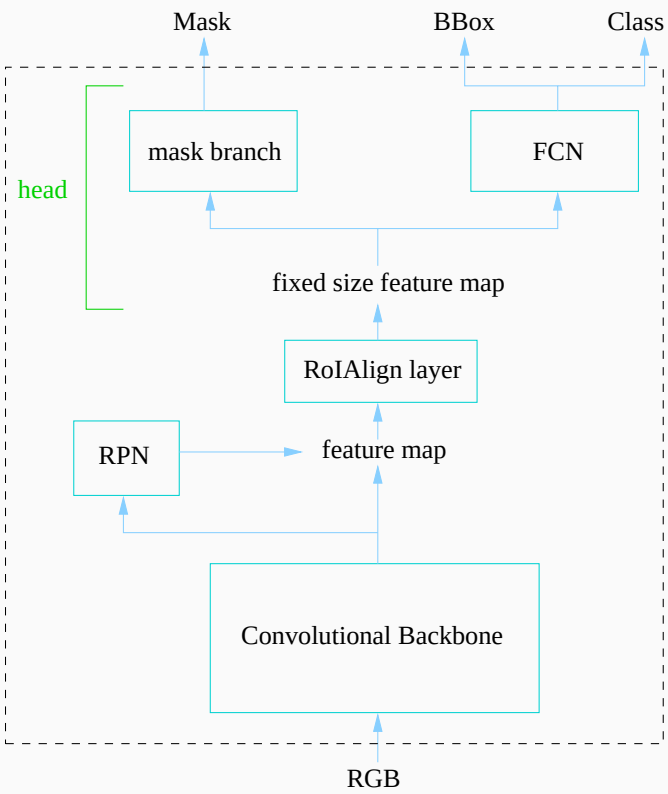


Mask R-CNN Detection Module

Mask R-CNN Module



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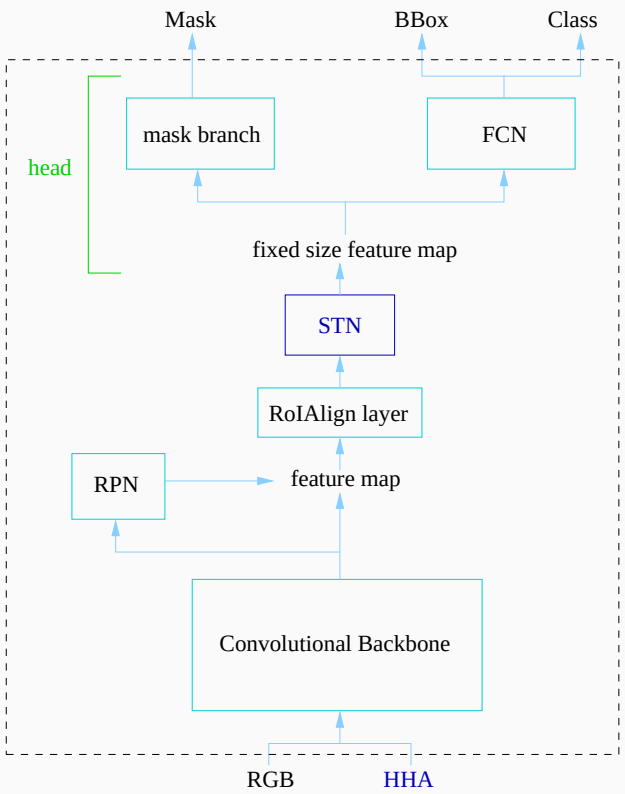
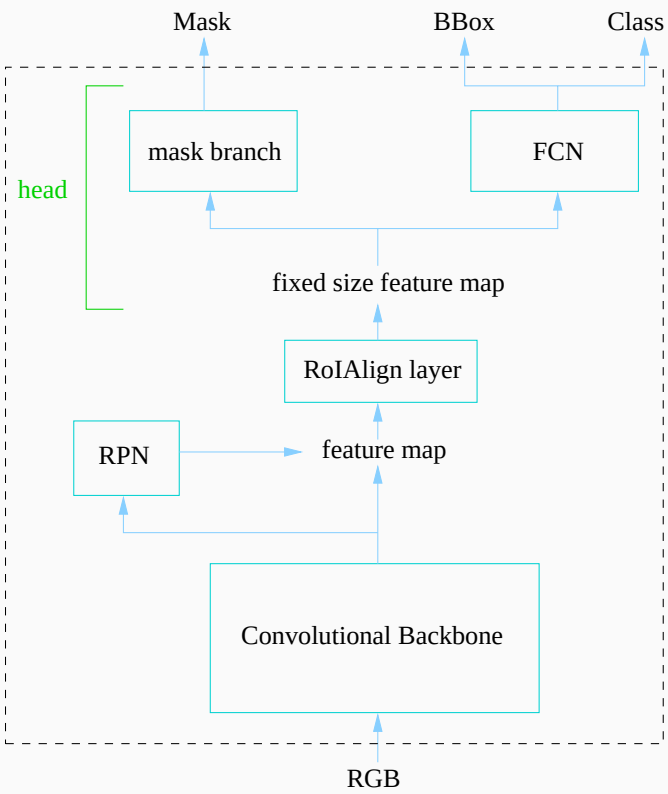


Mask R-CNN Detection Module

- 引入 HHA，有效利用三维信息，解决原算法难以检测纹理缺少的物体

Mask R-CNN Module



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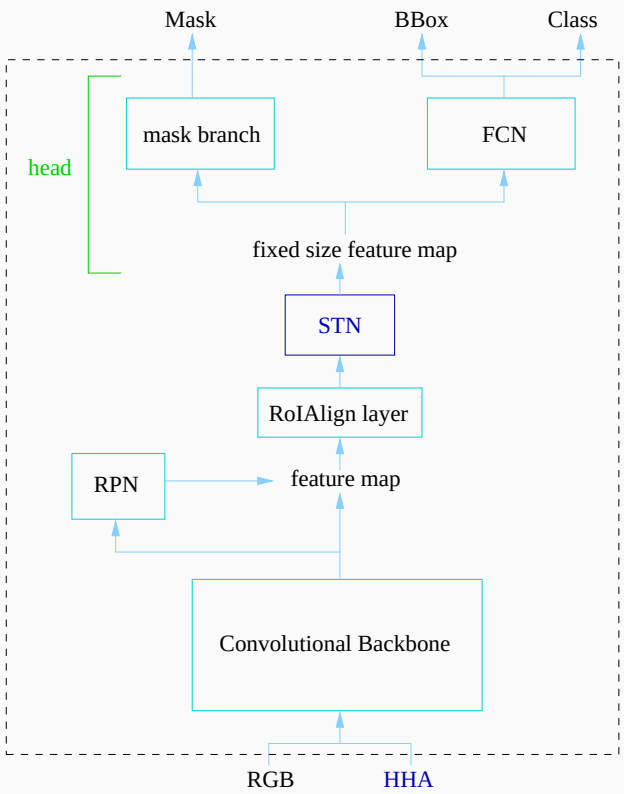
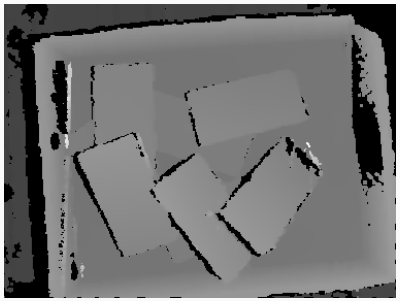


Mask R-CNN Detection Module

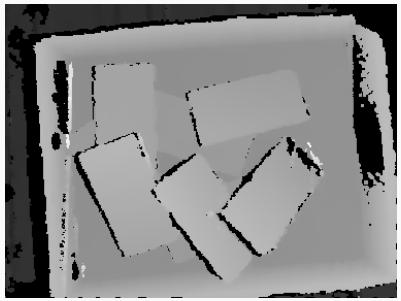
- 引入 HHA，有效利用三维信息，解决原算法难以检测纹理缺少的物体
- 在网络中增加 STN(Spatial Transformer Network)，使得提取的特征具有旋转不变性，增加了算法检测准确度

Detection Module

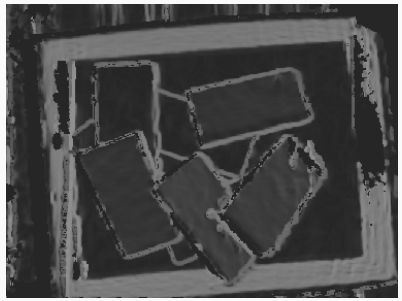
Detection Module



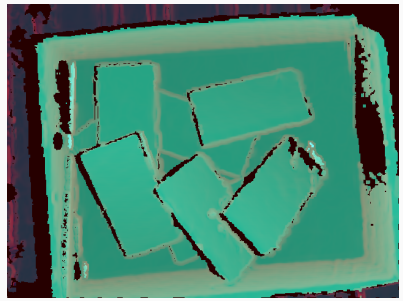
Horizontal disparity frame



Height above ground frame

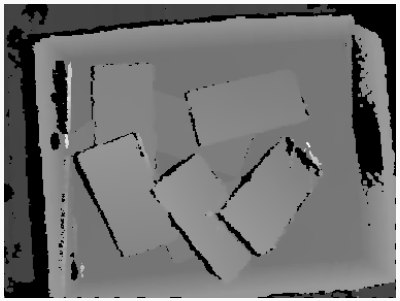


Angle with gravity frame



HHA frame

Detection Module



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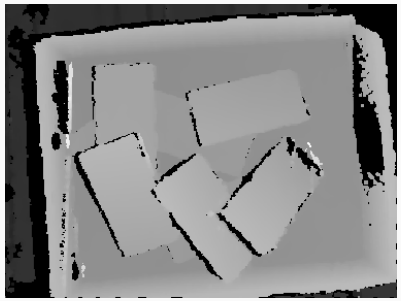

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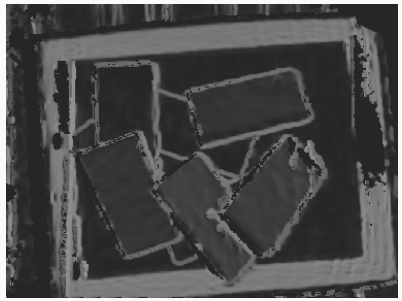

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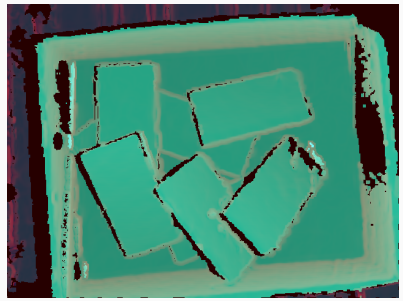
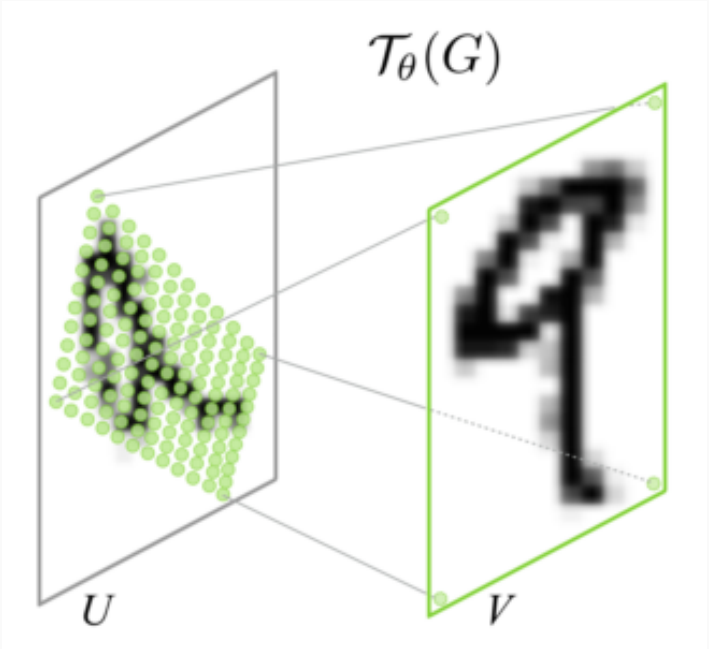


HHA frame



Detection Module Results

Detection Module Results

表 1: APC 数据集上的精确度

	input	output	AP	$AP_{0.5}$	$AP_{0.75}$
Faster R-CNN	RGB	bbox	33.26	56.29	34.03
Our method(based on Faster R-CNN)	RGB+HHA	bbox	**34.55**	**57.99**	**34.69**
Mask R-CNN	RGB	mask	32.34	55.78	33.12
Our method(based on Mask R-CNN)	RGB+HHA	mask	**33.94**	**56.45**	**33.99**

Detection Module Results

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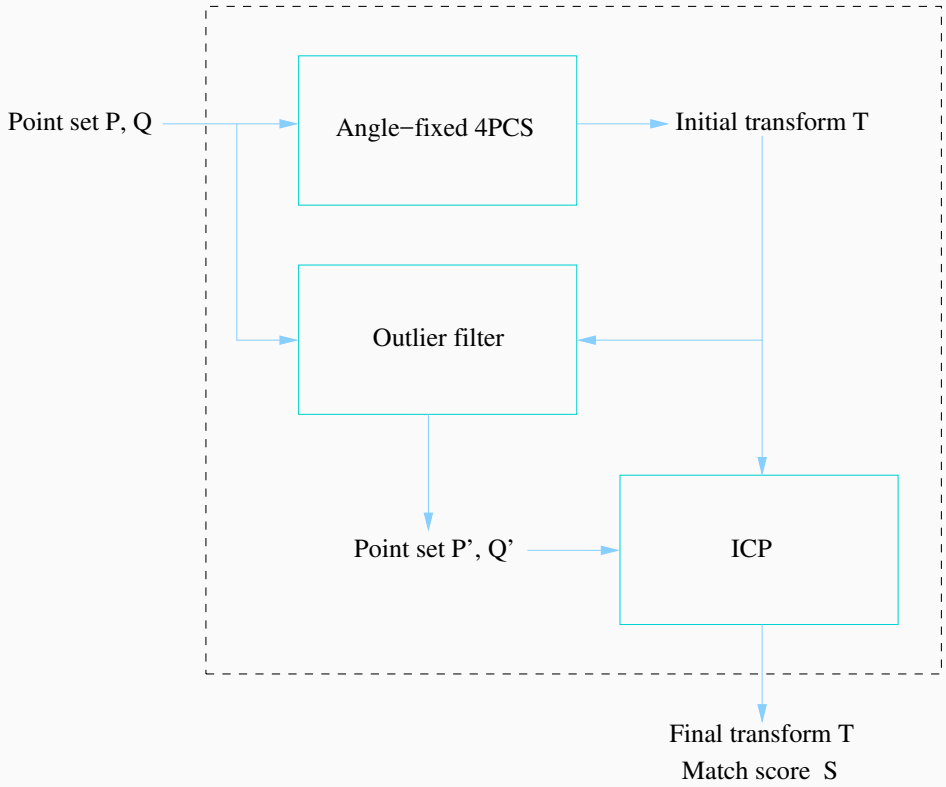
Mask R-CNN	RGB	mask	32.34	55.78	33.12
Our method(based on Mask R-CNN)	RGB+HHA	mask	**33.94**	**56.45**	**33.99**

表 2: workpiece 数据集上的精确度

	input	output	AP	$AP_{0.5}$	$AP_{0.75}$
Faster R-CNN	RGB	bbox	18.78	37.49	19.46
Our method(based on Faster R-CNN)	RGB+HHA	bbox	**32.39**	**56.37**	**33.54**
Mask R-CNN	RGB	mask	16.12	35.95	18.74
Our method(based on Mask R-CNN)	RGB+HHA	mask	**30.98**	**53.74**	**32.19**

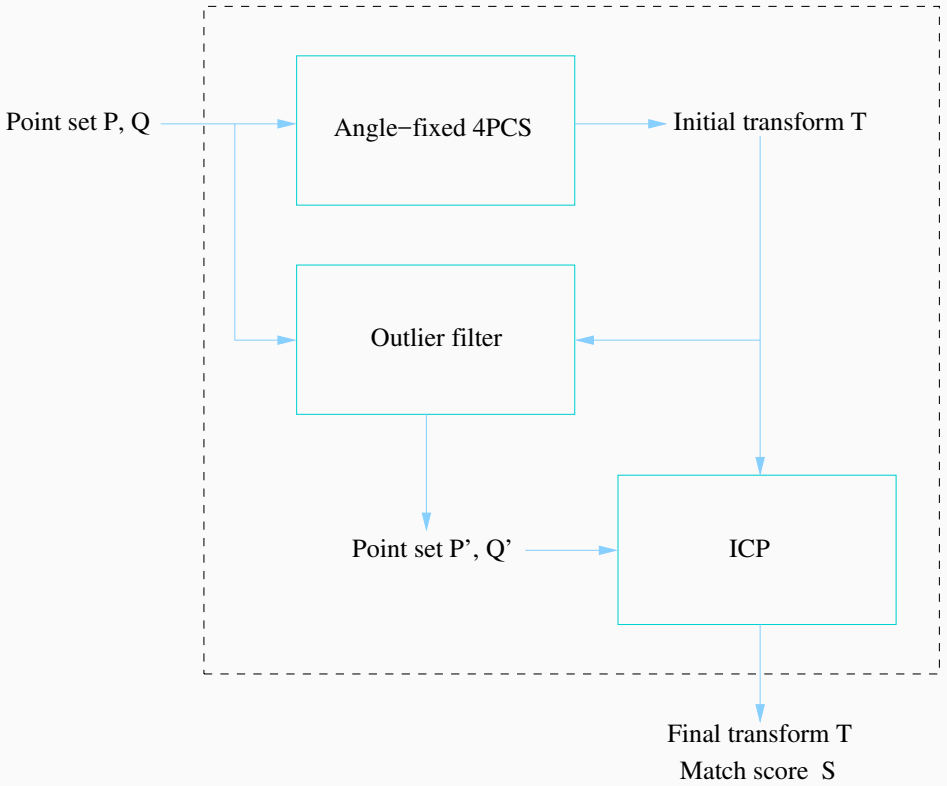
Matching Module

Matching Module



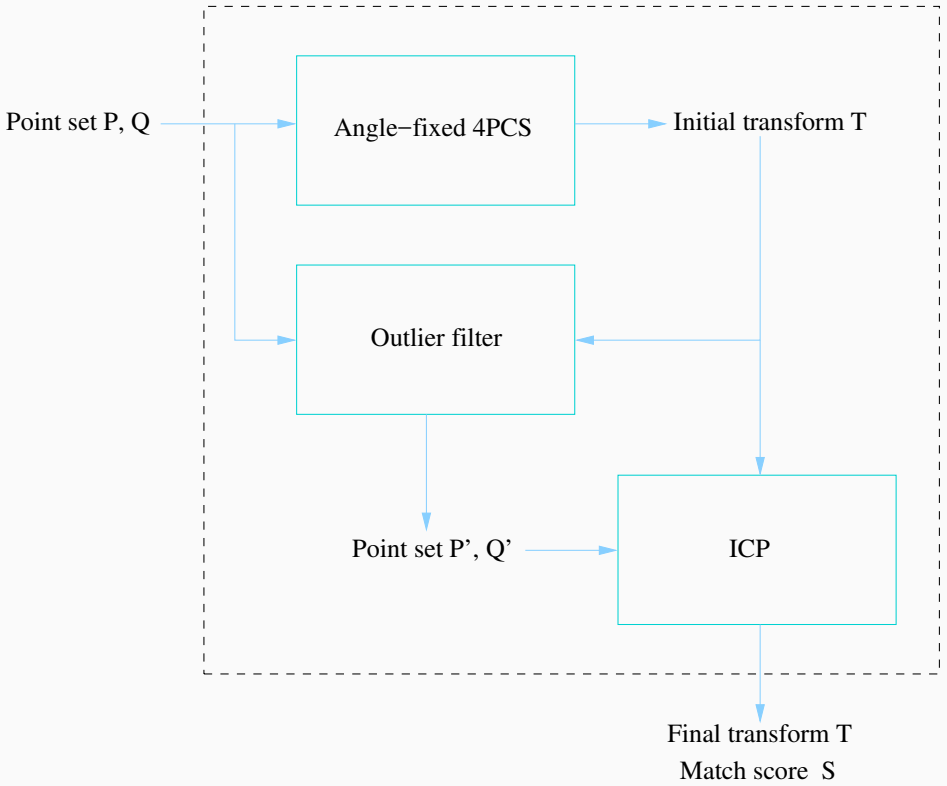
Matching Module

- 去除 4PCS 算法中角度不相等的基，减少了算法运算时间



Matching Module

- 去除 4PCS 算法中角度不相等的基，减少了算法运算时间
- 通过增加滤波和 ICP 算法，增加了匹配精度



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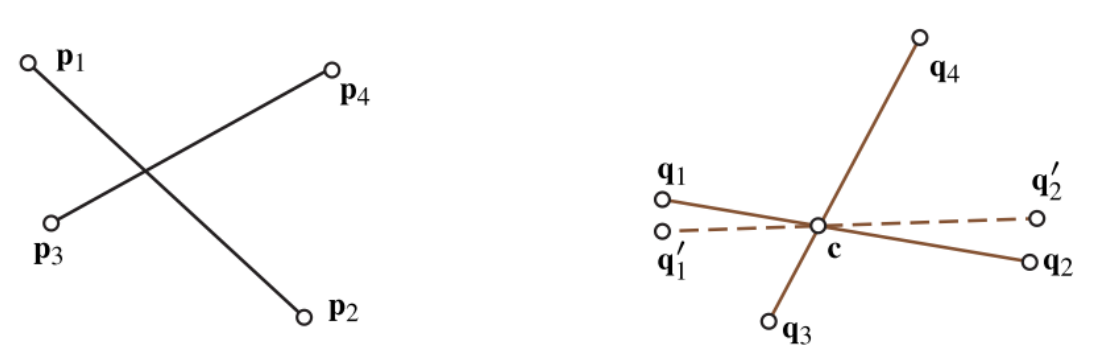
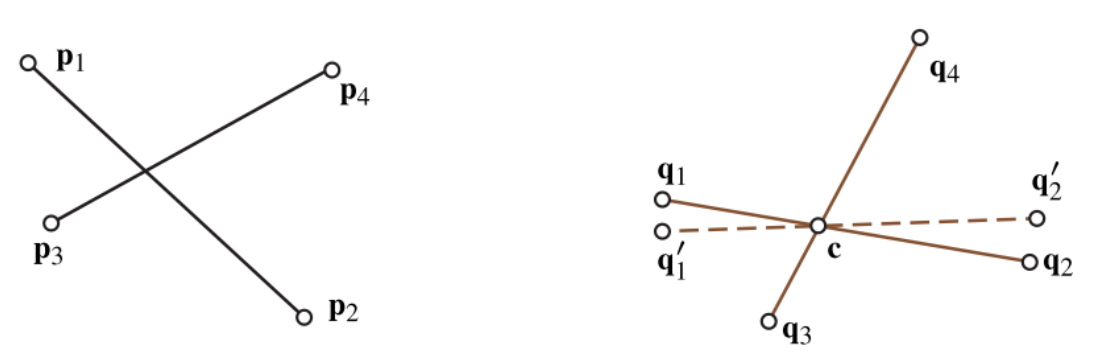
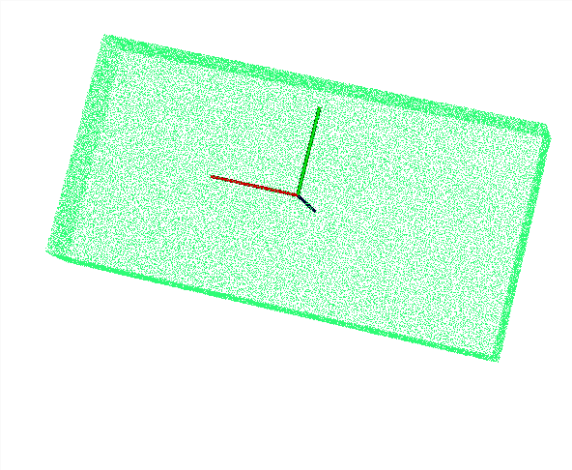


4PCS 存在的问题

Matching Module



4PCS 存在的问题

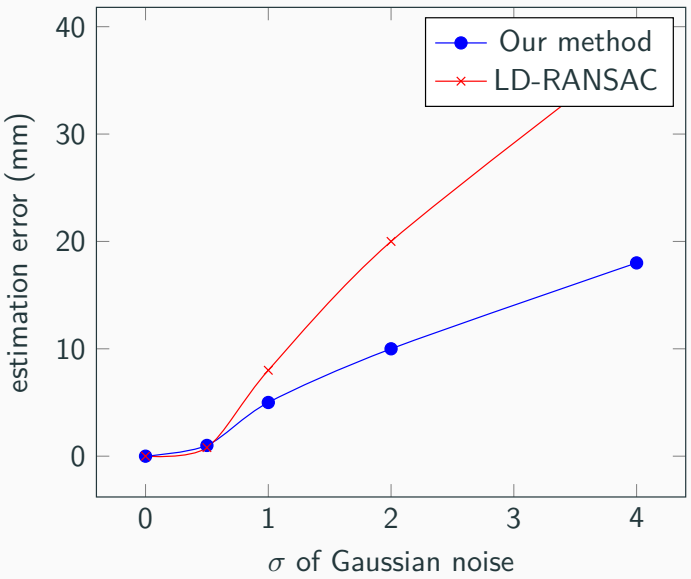


目标 3D 模型转化的点云

从 BBox 裁剪得到的点云

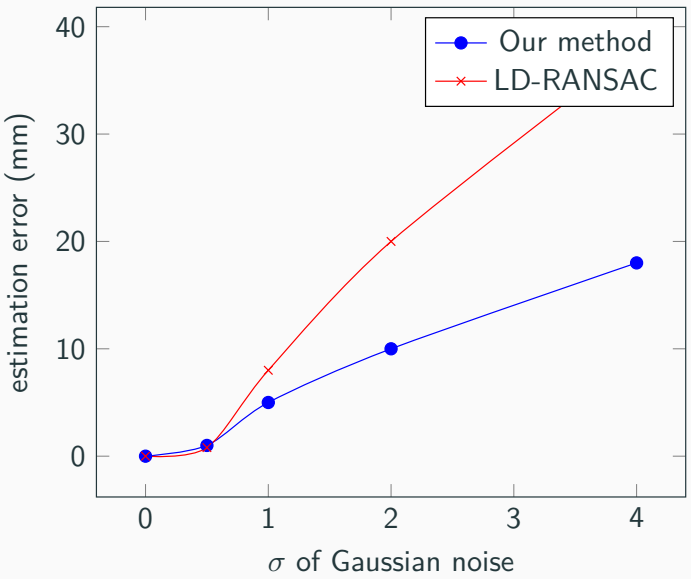
Matching Module Results

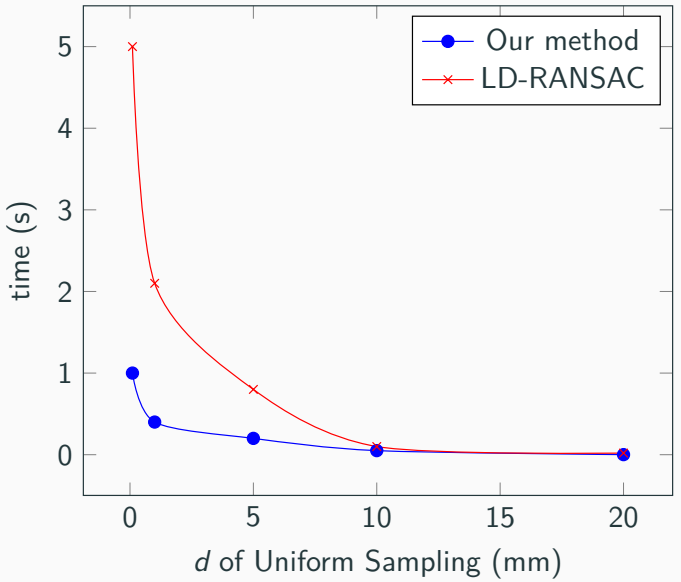
Matching Module Results



$$E = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \min_{p_j \in T(P)} \|q_i - p_j\|^2}$$

Matching Module Results





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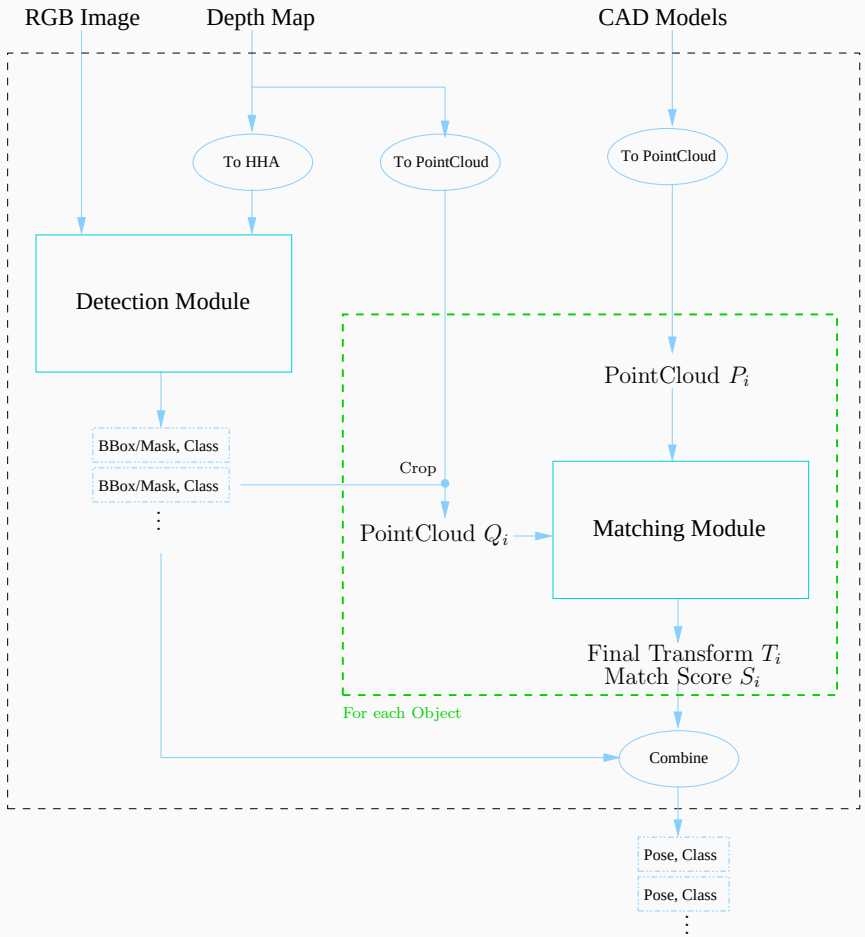
$d \uparrow$, the size of point cloud $\downarrow$

Combine Everything



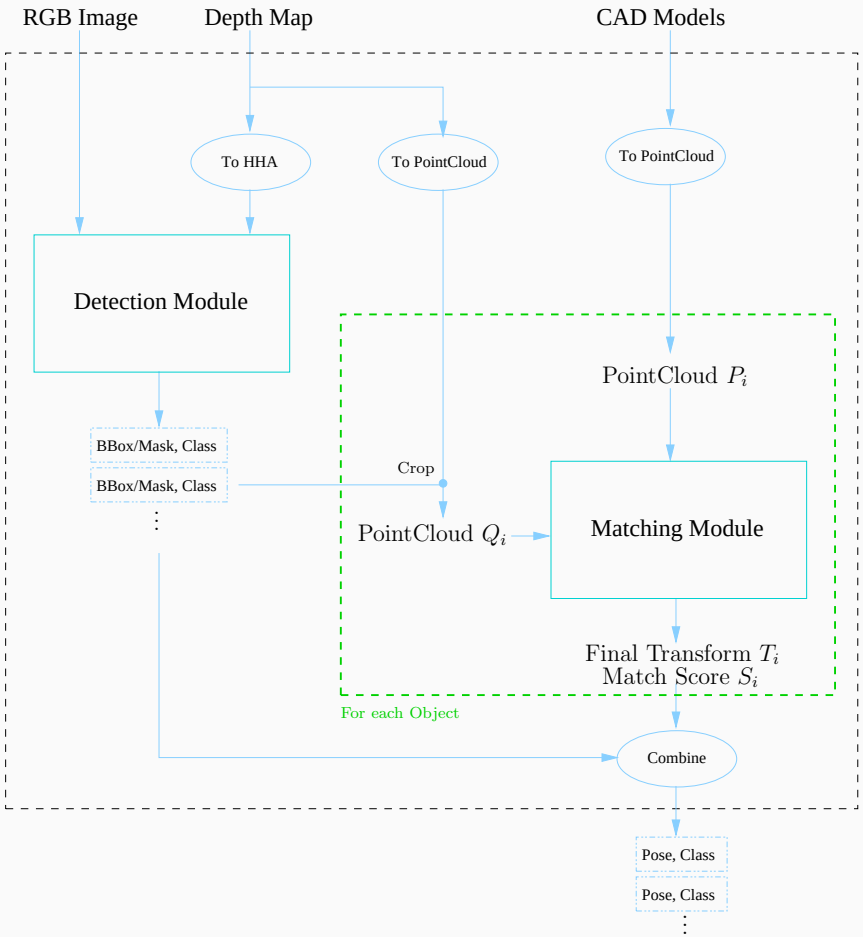
Combine Everything

算法 2: 3D-MRAI 算法

Input: RGB Image I, Depth Map D, CAD Models M

Output: Set of Pose and Class Res

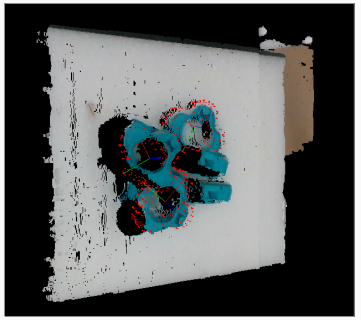
$Res \leftarrow \varnothing$;
$P \leftarrow \varnothing$;
forall $M_i \in M$ **do**
    $P \leftarrow \{P, CAD2PointCloud(M_i)\}$;
$H = Depth2HHA(D)$;
$Q = Depth2PointCloud(D)$;
$Mask, Class \leftarrow DetectModule(I, H)$;
forall $m_i \in Mask, c_i \in Class$ **do**
    $Q_i \leftarrow Crop(Q, m_i)$;
    $P_i \leftarrow P(c_i)$;
    $T_i, S_i \leftarrow MatchModule(P_i, Q_i)$;
    if $S_i > S_{min}$ **then**
        $Res \leftarrow \{Res, [T_i, c_i]\}$;
return Res



3D-MRAI Results

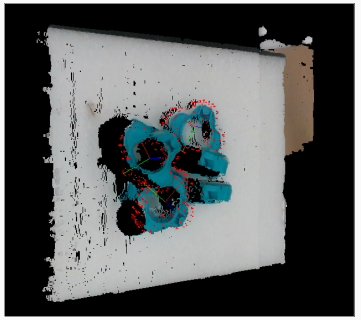
3D-MRAI Results





3D-MRAI Results

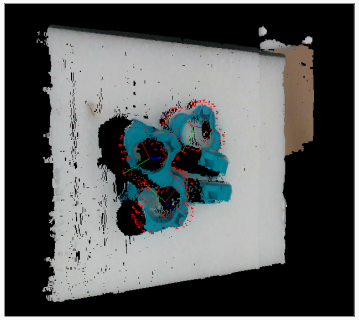




k_m[%]	5	7	9	11	13	15
Hinterstorisser et al.	75.63	83.84	89.13	93.48	96.83	98.12
3D-MRAI	95.12	97.35	98.10	98.69	99.22	100.00

3D-MRAI Results





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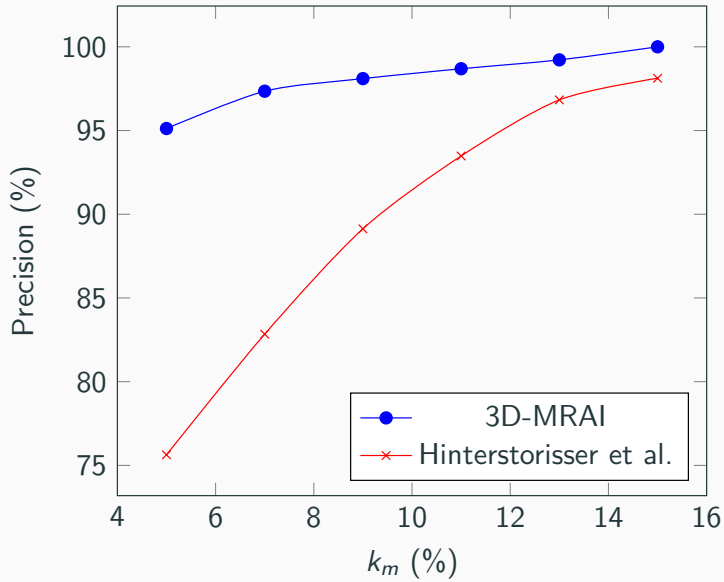
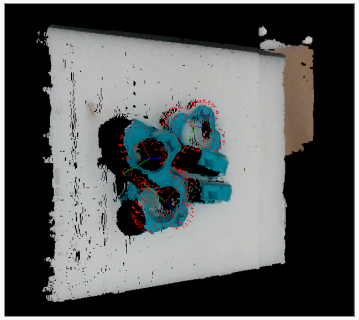


3D-MRAI Results





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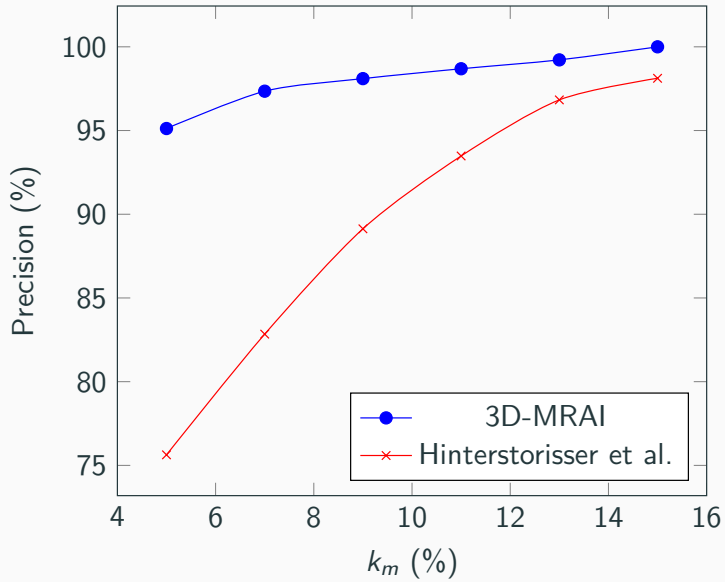
$$m = \underset{\mathbf{x} \in M}{avg} \parallel (R\mathbf{x} + t) - (\tilde{R}\mathbf{x} + \tilde{t}) \parallel$$

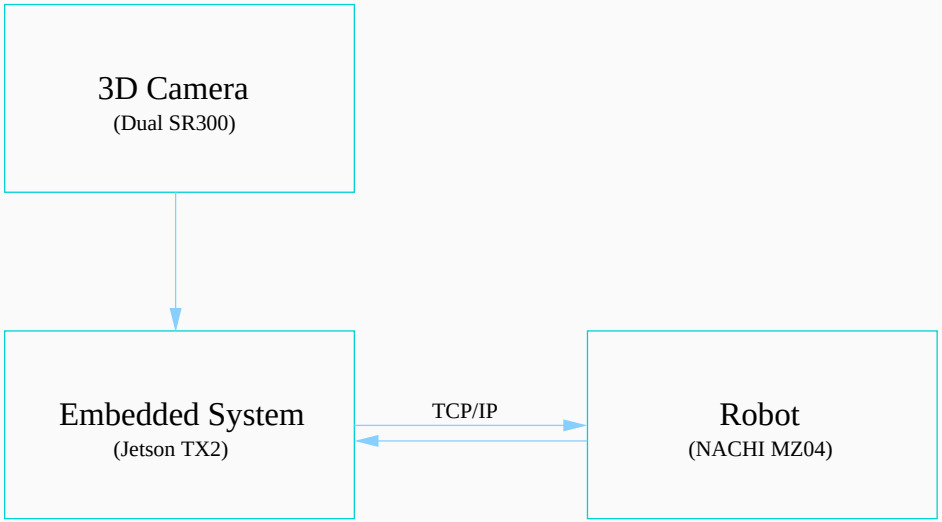
如果 $m < k_m d$，算法输出位姿正确



Application: Bin-picking

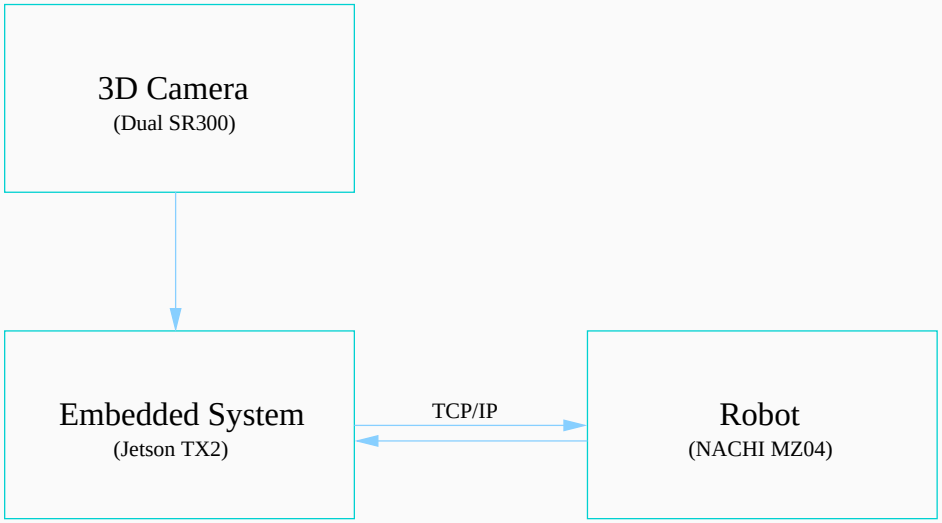
System Structure

System Structure



硬件架构

System Structure



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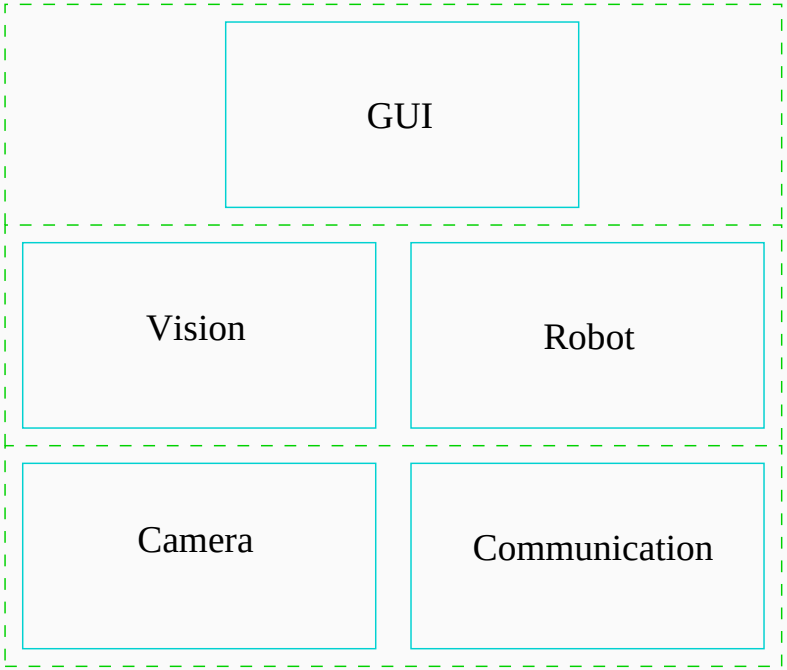
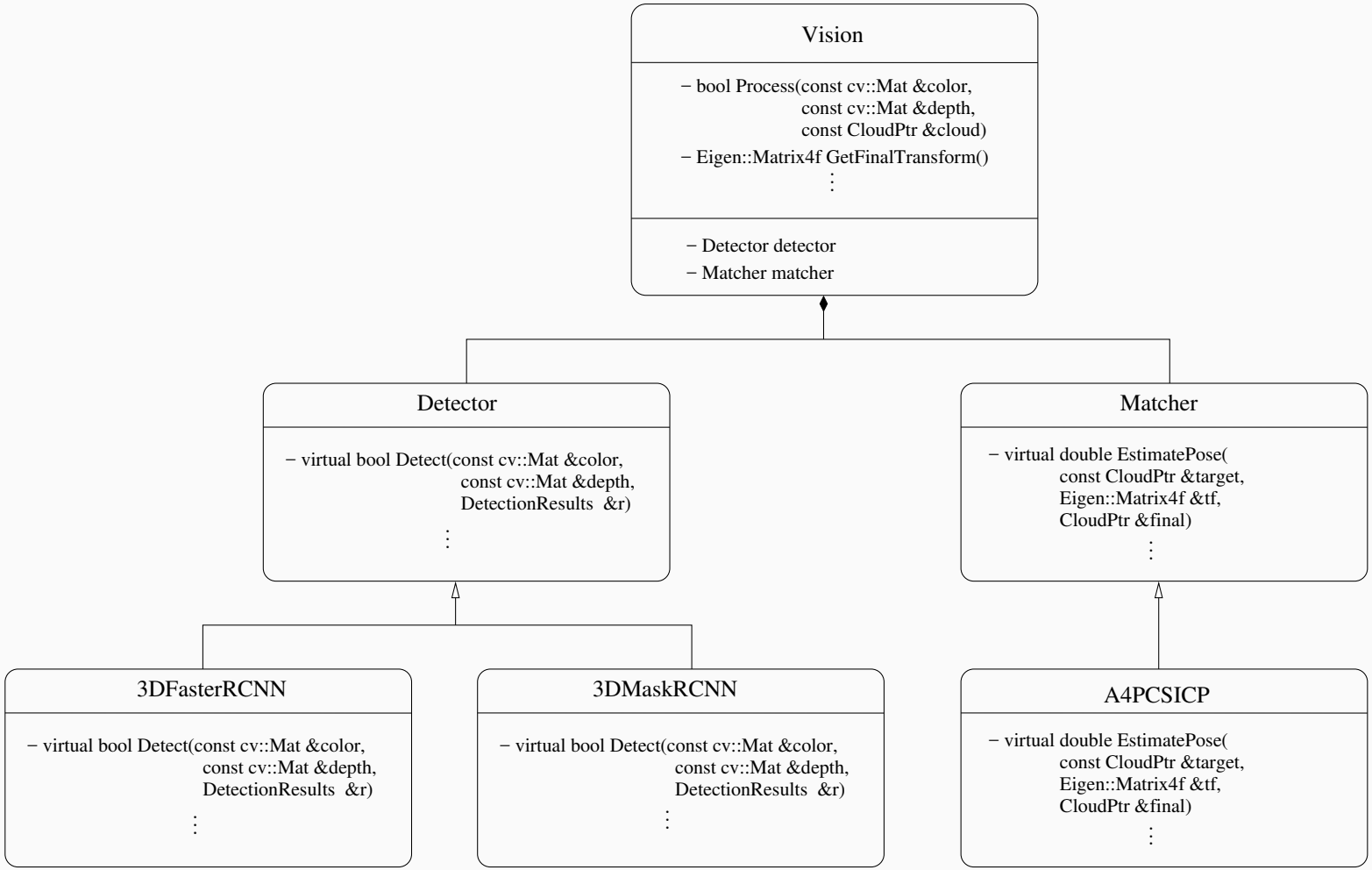


软件架构

Design Example

Design Example



Experiment

Experiment

实验环境

Experiment

实验环境

物料箱

Experiment & Results

Experiment & Results

	成功率 R	响应时间 T_r	抓取时间 T_1	放置时间 T_2	工作周期 T
1	100%	711ms	7.6s	4.2s	11.9s
2	100%	729ms	6.8s	4.2s	11.0s
3	100%	708ms	6.5s	4.2s	10.7s
4	100%	701ms	8.1s	4.2s	12.3s
5	100%	713ms	9.3s	4.2s	13.5s
6	100%	722ms	6.6s	4.2s	10.8s
7	100%	693ms	7.9s	4.2s	12.1s
8	100%	732ms	9.1s	4.2s	13.3s
9	100%	718ms	8.9s	4.2s	13.1s
10	100%	723ms	6.9s	4.2s	11.1s
Avg.	**100%**	**715ms**	**7.77s**	**4.20s**	**11.98s**

Experiment & Results

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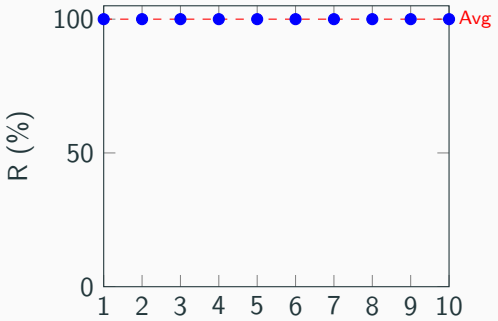
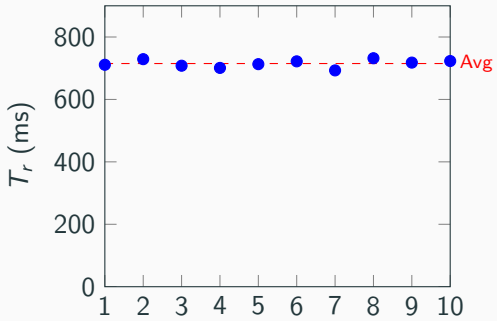
$$T = T_1 + \max(T_r, T_2)$$

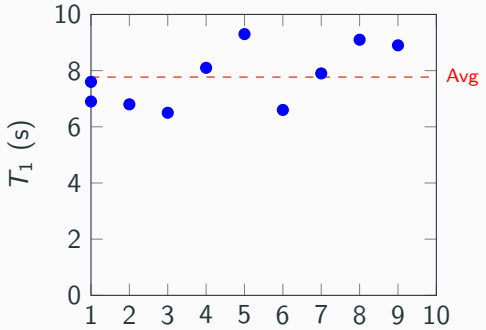
Experiment & Results



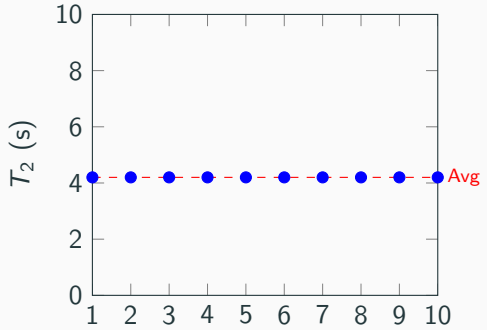
(a) 抓取成功率



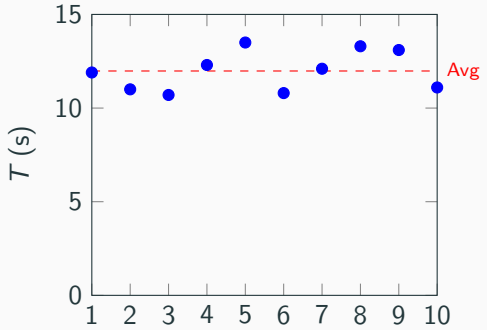
(b) 响应时间



(c) 抓取时间



(d) 放置时间



(e) 工作周期

Conclusion

Summary

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- 对偶 RGB-D 相机结构相比单个 RGB-D 相机有更高的填充率，更低的噪声，但对精度的提升不明显

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- 3D-MRAI 算法相比传统算法表现出了较高的检测准确率，估计的位姿精度也更高，但 FPS 较低
- 基于 3D-MRAI 算法设计的 Bin-Picking 视觉系统具有更高的抓取成功率、更快的响应速度，以及更低的成本

Questions?