Efficiently Registering Depth and RGB Images

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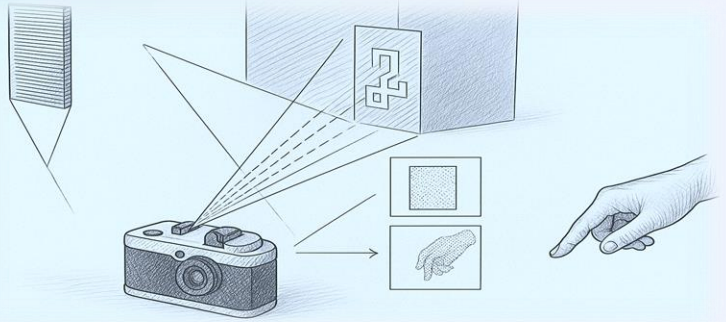

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Years
30

Employees
3,500+
Engineers

Locations

16	85	347	750	100M
Design Centers	**Countries**	**Locations**	**Products**	**Deployments**

CERTIFICATIONS & QMS Compatibility

CMMI-DEV v2.0 Level-3 CMMI-SVC v2.0 Level-3 Automotive SPICE VDA SW	ISO 27001 : 2013 ISO 20000-1 : 2018 ISO 9001 : 2015 ISO 13485 : 2016	DO-178B/C DO-254 ISO 26262 AS 9100D	IEC 60601 - 1 IEC 62304 ISO 14971 IEC 62366

PARTNERSHIPS

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EIC's service offerings

	DEVICE	DIGITAL	QUALITY	SILICON
INNOVATE	Hardware Design	Full Stack IoT Implementation	Vision-Based Test Automation	ASIC/FPGA Design, DV & DFT
	Embedded & Multimedia	Cloud/Mobility Led Business Model Innovation	Cognitive QA	IP Development
TRANSFORM	Re-engineering	Legacy Modernization	QAOps	Derivative ASICs
	Value Engineering	Digital Transformation		Lower Node ASICs
SCALE	Manufacturing	Platformization	QA Automation	Reference Designs
	Sustenance & Support	Process Automation	Certification Services	Turnkey Silicon Design

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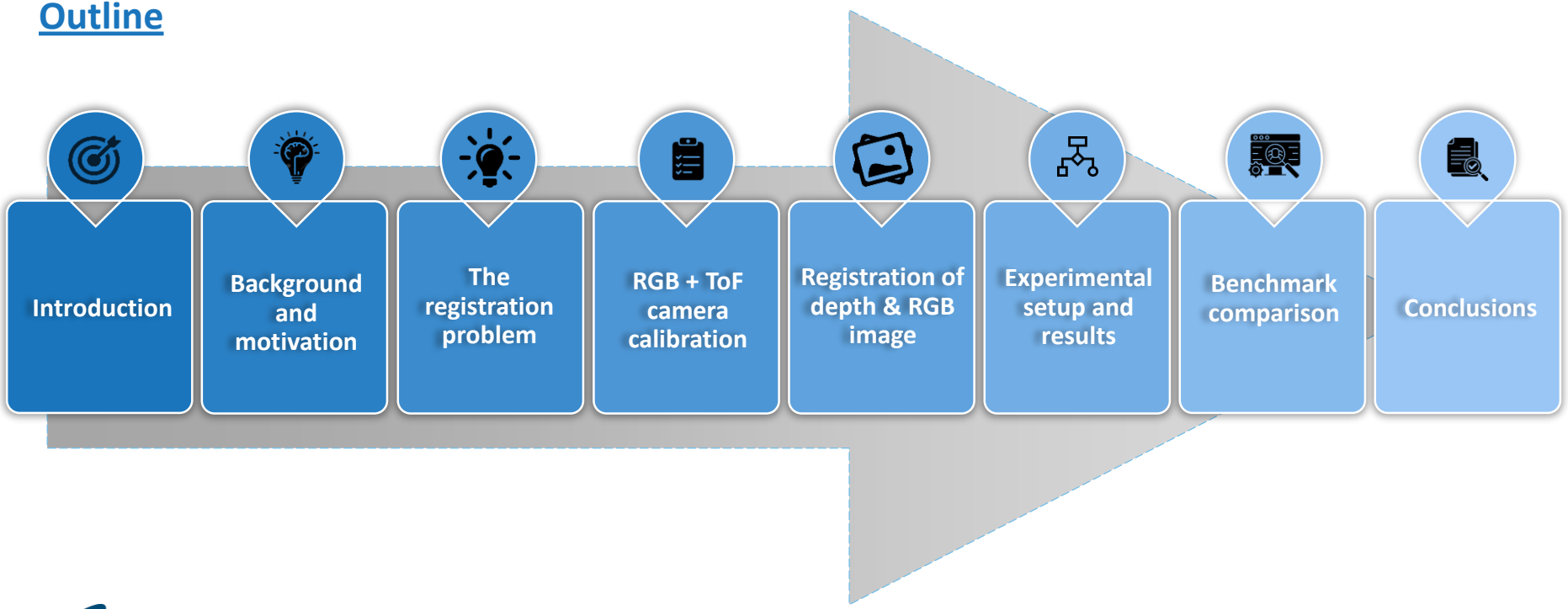
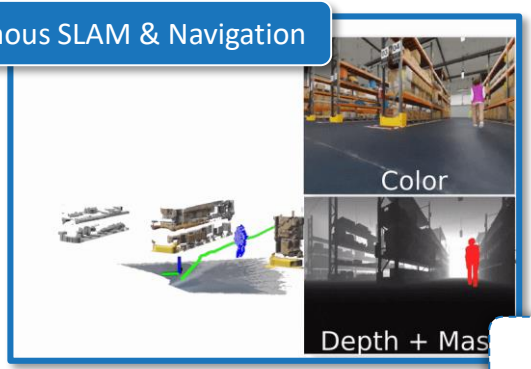
Efficiently registering depth and RGB images

Outline



Introduction

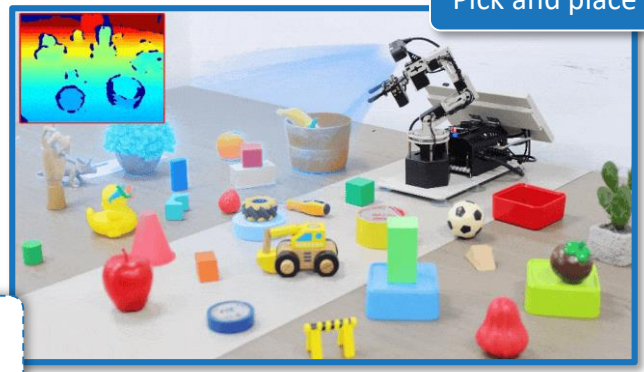
Autonomous SLAM & Navigation



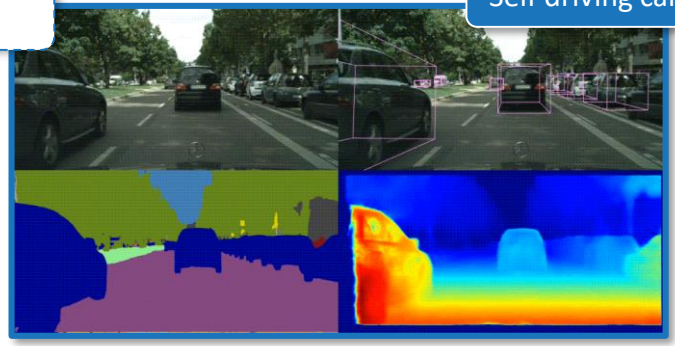
AR/VR 3D reconstruction

Either an RGB camera or a Depth camera is insufficient for these practical applications.

Pick and place



Self driving cars



Introduction

RGB-D camera:

An RGB-D camera is a type of imaging device that captures both:

- **RGB Image:** provides appearance, texture, and color of the scene
- **Depth Image:** provides distance, geometric structure, scale

Examples of RGB-D cameras

Key Components:

- RGB Sensor – captures color image
- Depth Sensor – captures per-pixel distance (via ToF)
- Calibration and alignment – align depth and RGB images using calibration parameters

Why choose an RGB-D camera?

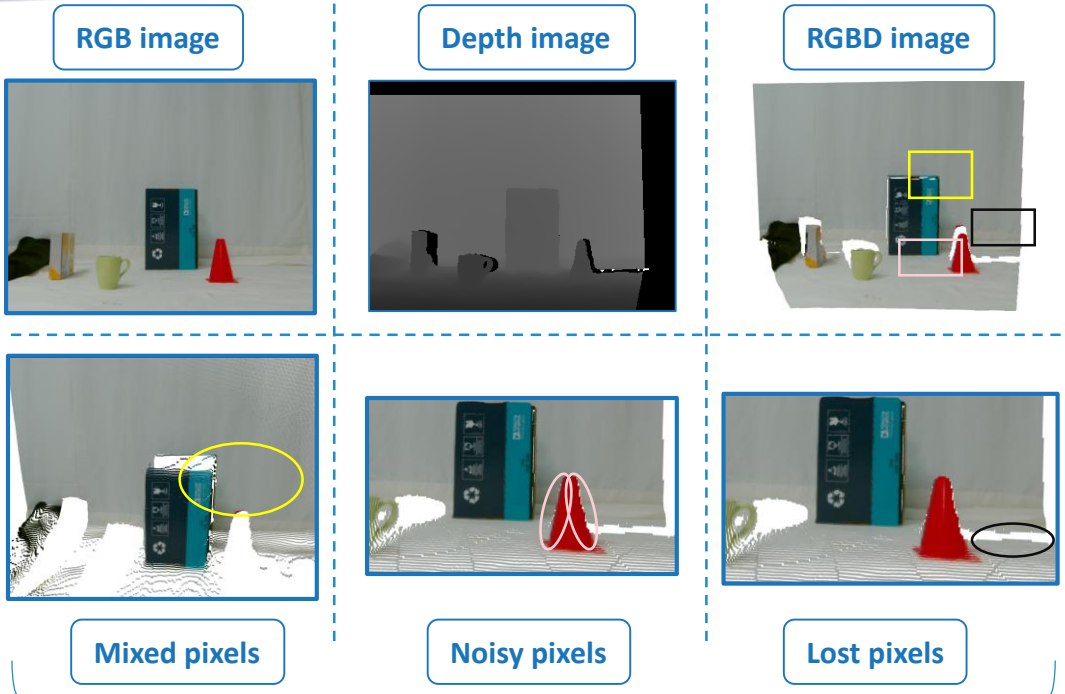
Feature	RGB + ToF depth (RGB-D) camera	RGB + RGB (Stereo) camera	Depth camera	RGB camera
Color information	**Yes**	Yes	No	Yes
Depth information	**Yes**	Yes	Yes	No
Performance in low Light	**Good**	Limited	Good	Limited
Odometry estimation	**Reliable**	Reliable	Not reliable	Not reliable
Depth accuracy	**Hardware-based precision in mm**	Depends on resolution, baseline	Hardware-based precision in mm	No depth info
SLAM and navigation	**Reliable (with depth info)**	Reliable (with good calibration)	Challenging (no color info)	Challenging (2D features)
3D reconstruction	**Textured 3D models**	Requires good lighting/textures	Shape only	Texture only
AI/ML	**2D and 3D**	2D and 3D	Only 3D	Only 2D
Computational Overhead	**Moderate**	High	Low	Low

Background and motivation

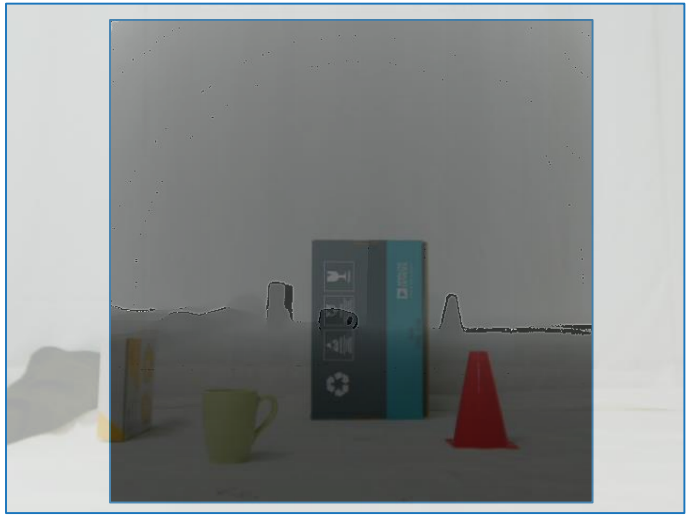
Challenges in RGB-D camera:

- Different resolution and FoVs
- Viewpoint and intrinsic matrixes are different
- Achieve real-time performance

Objective: To efficiently register depth image with RGB image by leveraging intrinsic and extrinsic parameters



The registration problem

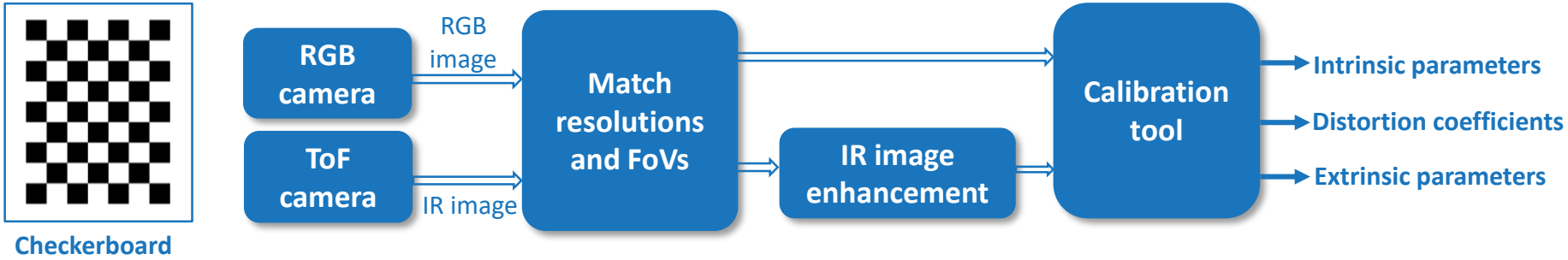


Misaligned RGB and depth images with different resolutions and FoVs

- Calibration
- Undistort
- Match resolution and FoV
- Registration

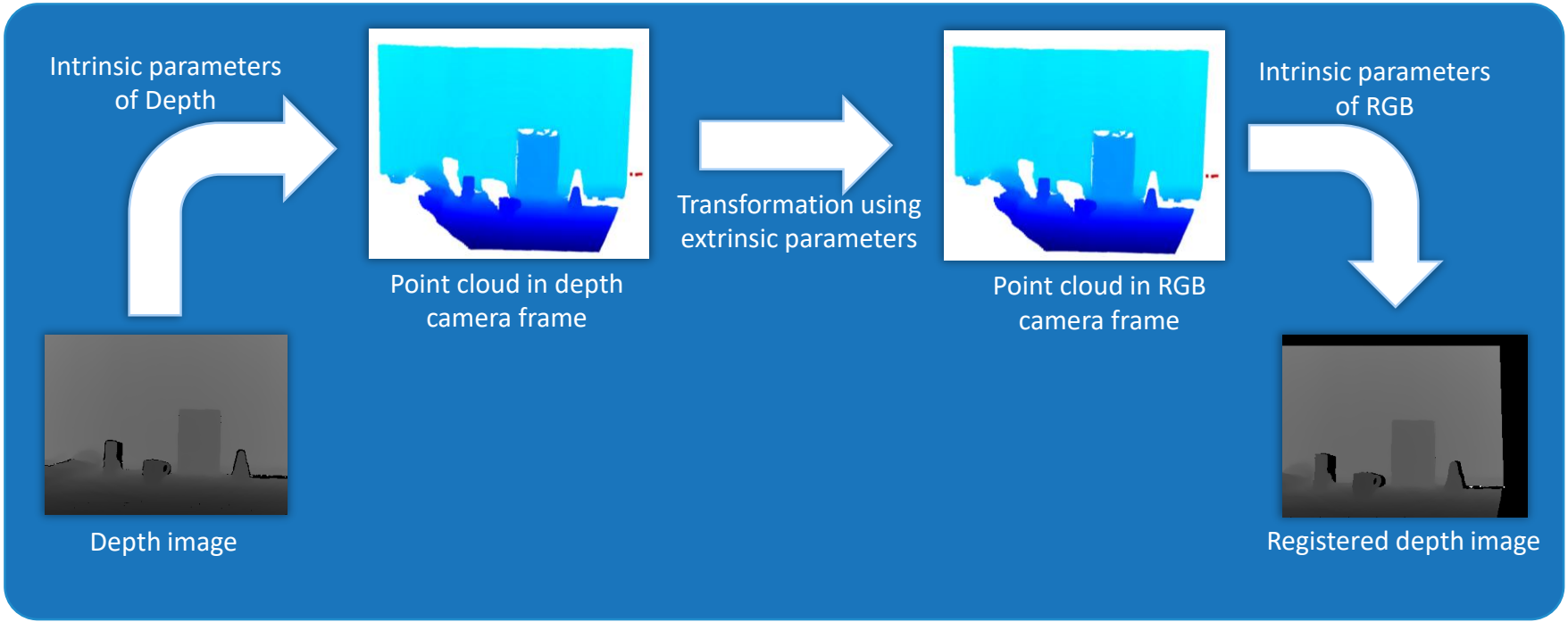
Aligned RGB and depth images

RGB + ToF camera calibration



- Calibration tools available are MATLAB, OpenCV and ROS.
- Capture the checkboard images from different positions and orientations.
- ToF camera captures the IR images and depth images. IR images are used for calibration.

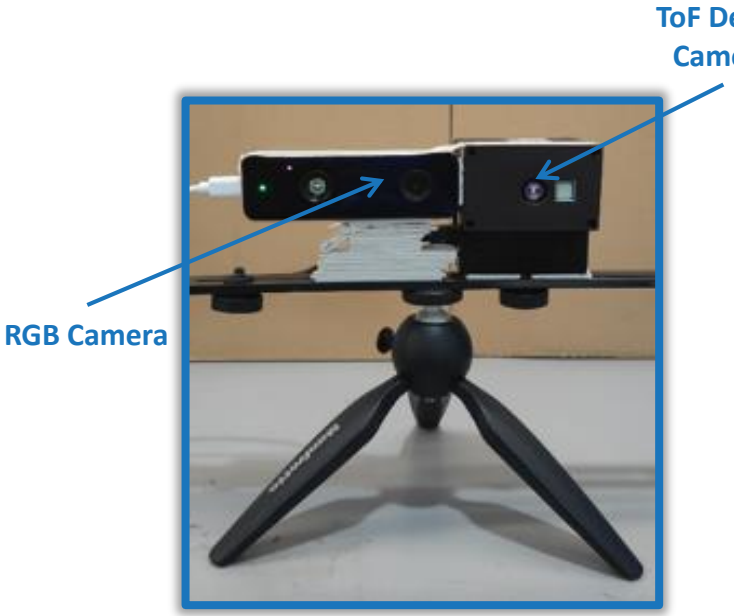
Registration of depth image and RGB image



Process flow of registration of RGB and depth camera

Experimental setup and results

Experimental Setup

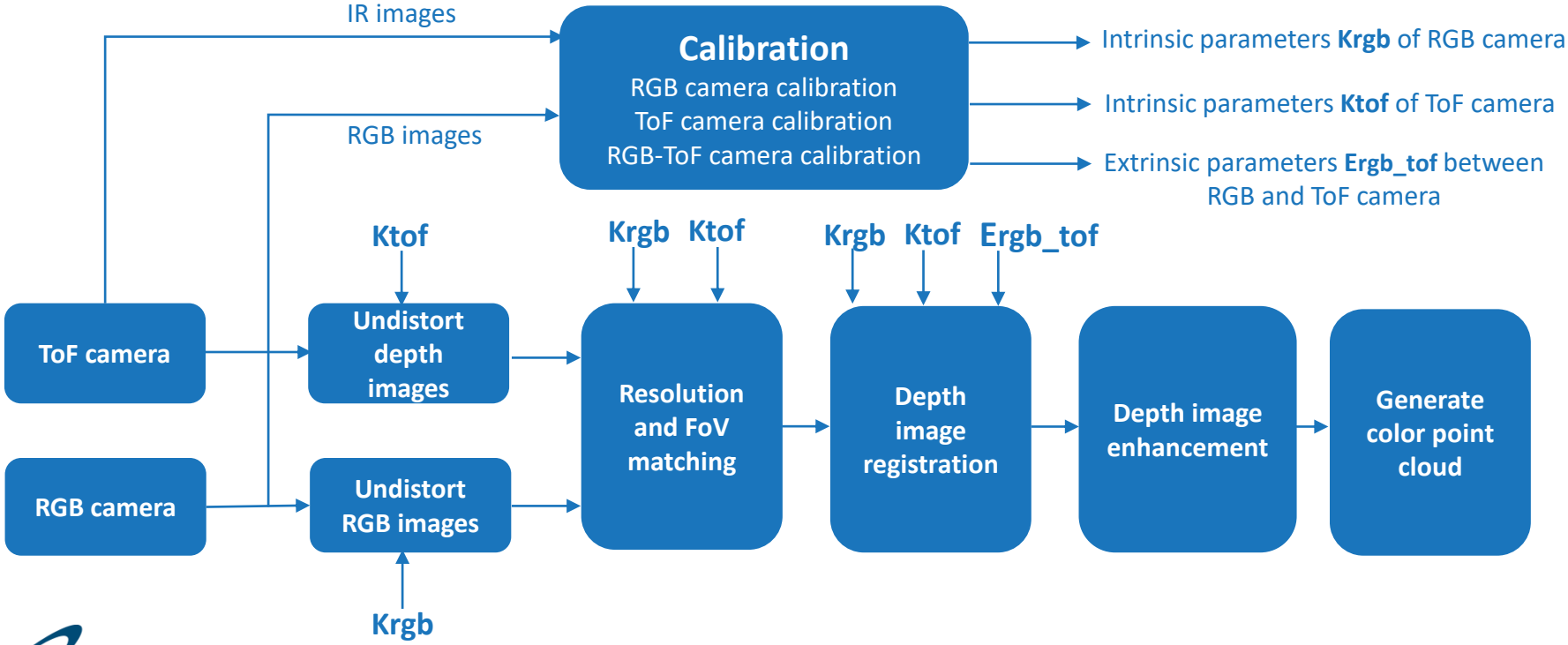


Experimental **RGB +ToF** camera setup

Specification of RGB camera and ToF camera

Specifications	ToF	RGB
Resolution	512×512	640x480
FoV	$75^{\circ} \times 75^{\circ}$	$73^{\circ} \times 42^{\circ}$
Range	0.4 to 4 m	NA
Depth accuracy	±5 mm	NA
Bandwidth	940 nm band-pass filter	Visible light (400–700 nm)

Software block diagram for RGB-D camera



Steps from captured images to registered image

RGB Image from RGB camera

Resolution matched RGB image

Resolution matched RGB image

Overlapped registered depth image with RGB image

Depth image from ToF camera

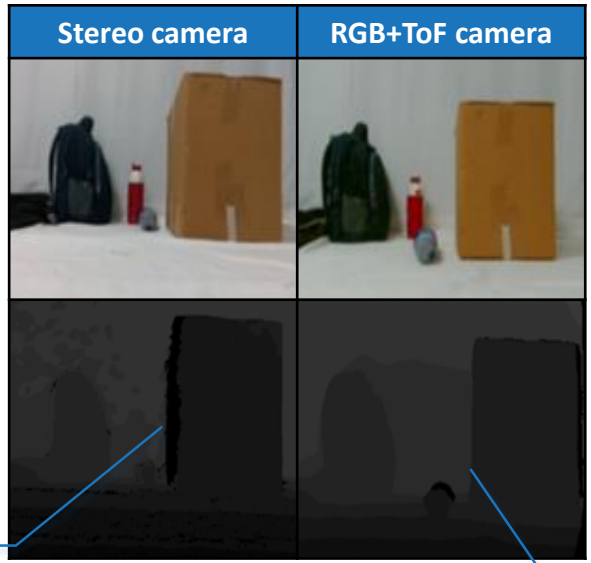
Resolution matched depth image

Registered depth image

Visualization of generated point cloud

Benchmark comparison

Normal light condition (100-1000 lux)



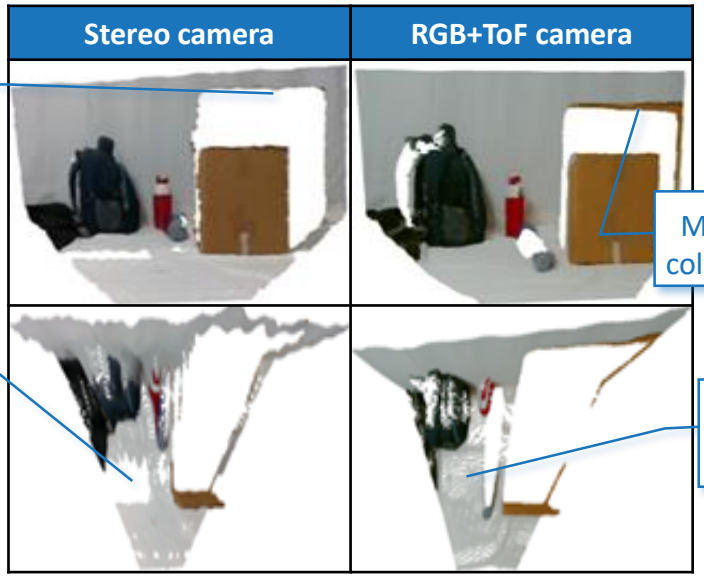
Rough and noisy edges

Smooth and clean edge

Registered Depth Images

Minimal color mixing

Moderate holes



Moderate color mixing

Few holes

Generated Point Clouds

No light condition (Approx 0 lux)

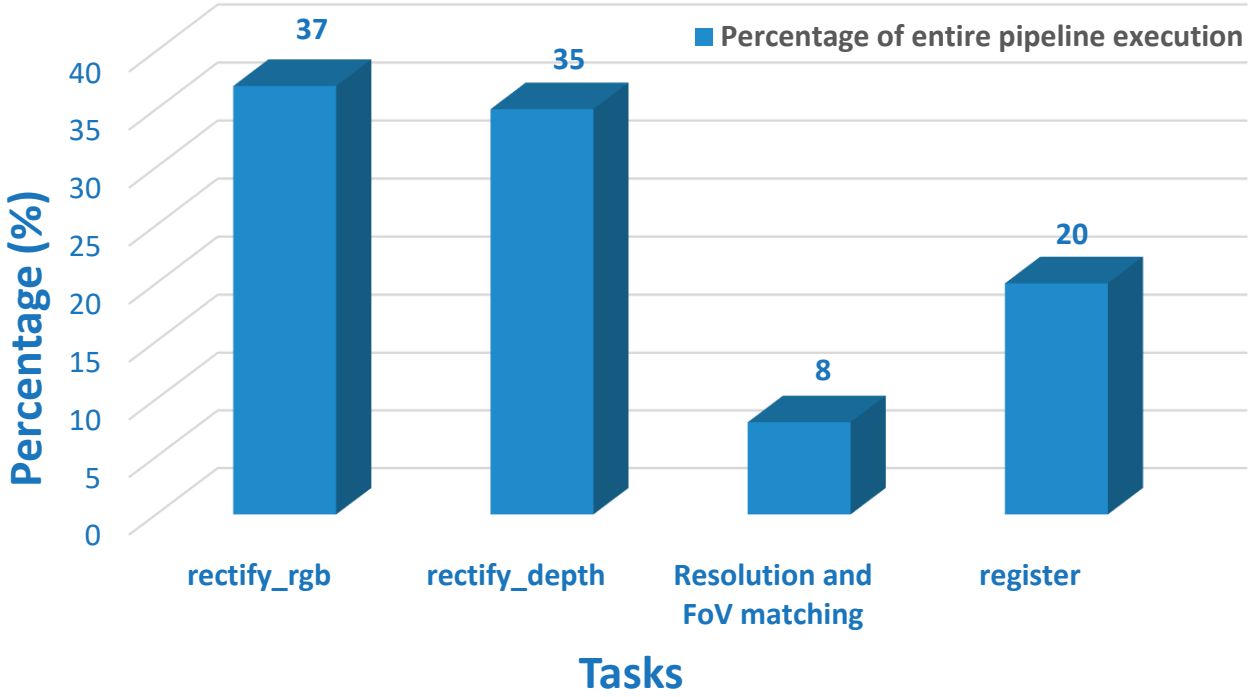
Stereo camera will not be able to generate meaningful pointcloud

RGB images

RGB+ToF camera generated a pointcloud with lesser number of noisy pixels

Registered Depth Images

Computation time analysis



Conclusions

1

2

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EIC's camera design capabilities

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New Product Development	Software/ Firmware	AI/ML & Cloud Enablement	Multimedia (Audio/Video)	Testing & Certifications
Embedded, Mechanical design, Sensor & optics selection, Custom SoC/SoM, BoM optimization, Manufacturing & sustenance	BSP development, ISP image tuning, Reusable camera framework, Mobile/Web app development, Cybersecurity	AI/ML on edge/cloud, Cloud-based video analytics, AI algorithm porting, CloudOps/DevOps, Managed services	Multi-sensor image/video stitching, Video compression, Latency and bandwidth optimization, Alexa/GA integration	Hardware testing (EDVT, thermal, functional, etc.), ONVIF/PSIA compliance Certification testing (i.e., FCC, CE, UL, PTCRB, IPxx etc.), QA & test automation

30+ Camera Designs (4K/IP/360°) | Partnerships with Qualcomm/Nvidia/NXP/TI | Access to OmniVision/Sony/Onsemi labs

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Resources

- DCAM710 Vzense
- Depth sensing in embedded vision
- S.E.Dhatrak, Sunil Kumar, “A Simple, Efficient and Complete Software Pipeline for Constructing an RGB-D Camera Using RGB and ToF Depth Cameras,” Proc. of the 11th Int. Conf. on Mechatronics and Robotics Engineering (ICMRE), Lille, France, Feb. 24–26, 2025.
- S. Kumar, S. Dhatrak, "Stereo Calibration of Heterogeneous RGB-ToF Camera for Robotics Applications," Proc. 6th Int. Conf. Artif. Intell., Robot., Control (AIRC), Savannah, GA, USA, May 7–9, 2025.

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Q & A