UI-SLAM: A Lightweight Multi-robot Collaborative SLAM System under Uneven Illumination Scenarios

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ABSTRACT

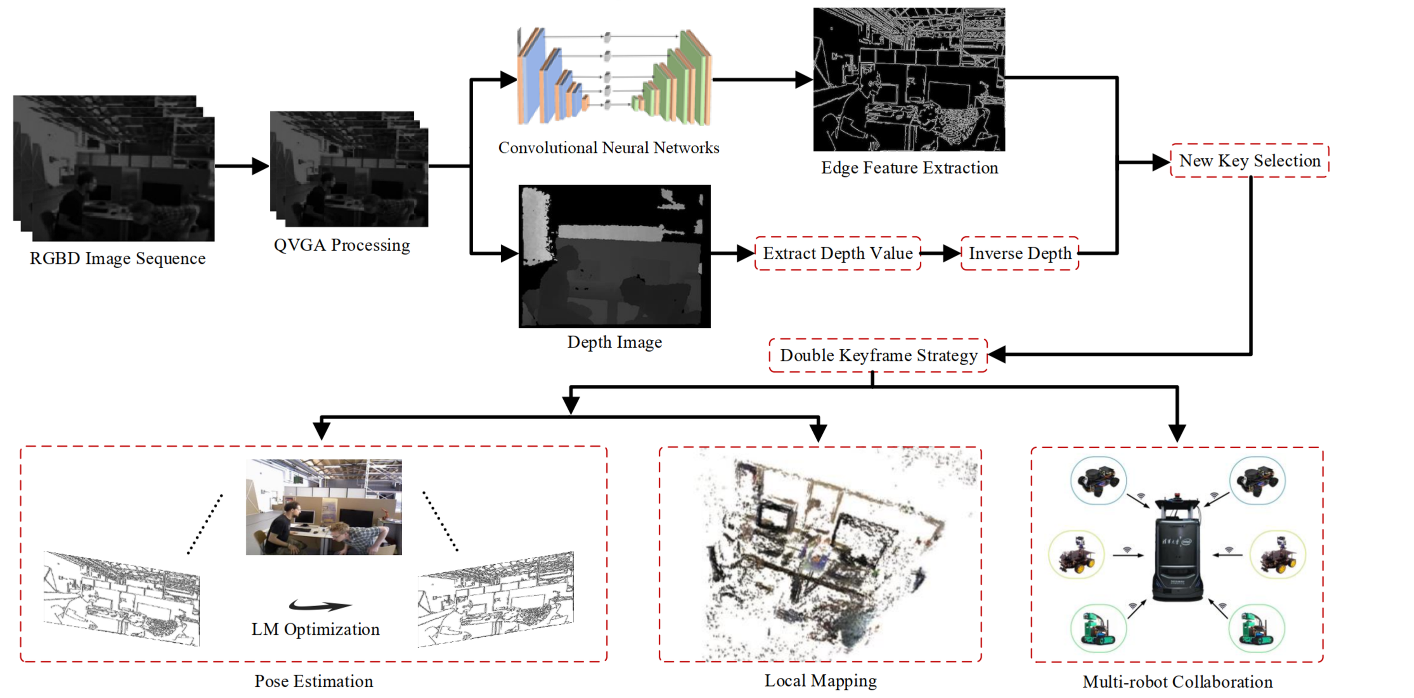
In uneven illumination scenes, it is difficult to simultaneous localization and mapping (SLAM) because of little information within the dark environment. To solve this problem, first, we propose a novelty visual odometry (VO) which can easily work in dark environments. Then, we propose a framework for multi-robot VO collaboration. Finally, we uses different algorithmic robots to fit different lighting conditions, solving the SLAM task with uneven lighting scenes.

INTRODUCTION

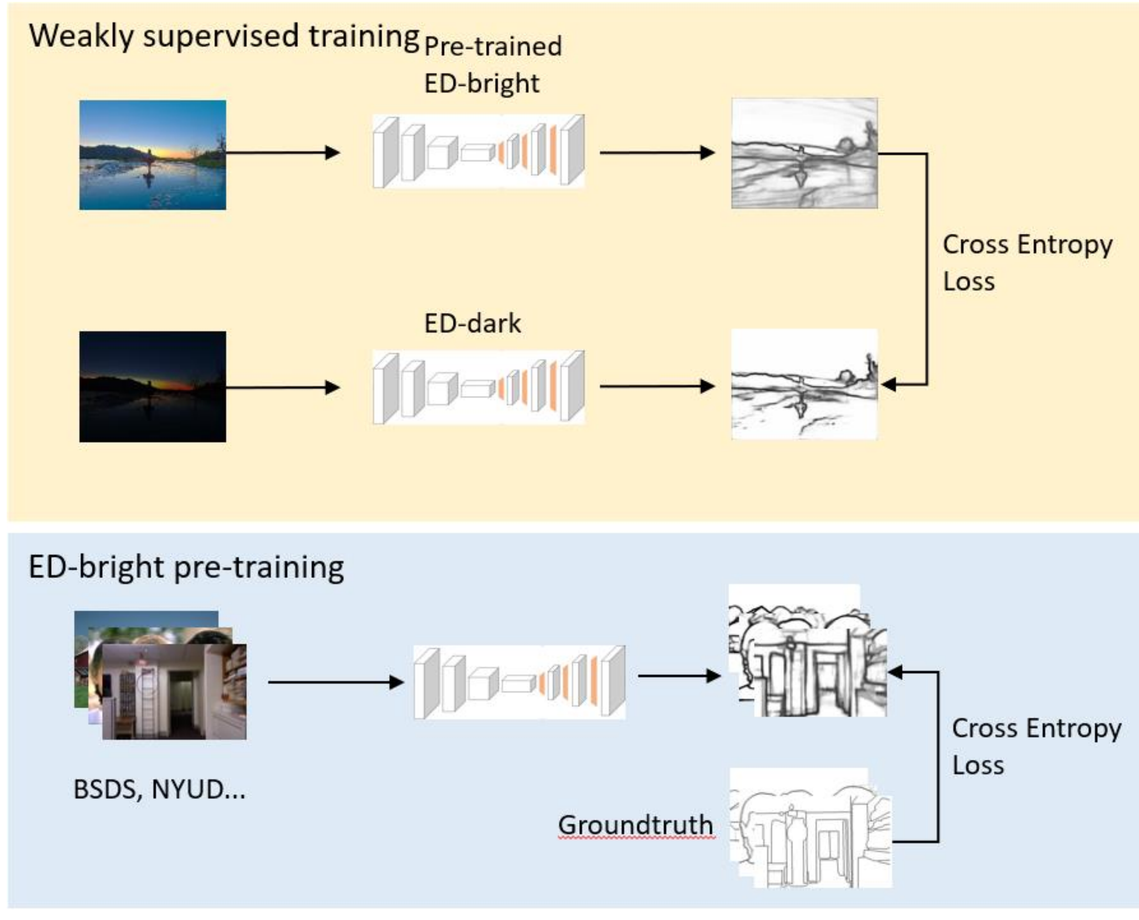
- **Background & problem states:** Visual SLAM always require the camera to continuously capture bright and clear images to successfully extract feature points or pixel alignment. However, once the acquired images are dark or unclear, the localization accuracy will be significantly decreased.
- **Challenges:** 1) how to implement SLAM in low illumination environment, and 2) how to build maps in large scenes with minimal resources in a collaborative multi-robot approach?
- **Solutions:** 1) a novelty vision odometry for low illumination environments in uneven illumination scenarios, and 2) a heterogeneous multi-robot collaboration framework with powerful and lightweight robots to avoid resource wastage.

METHOD

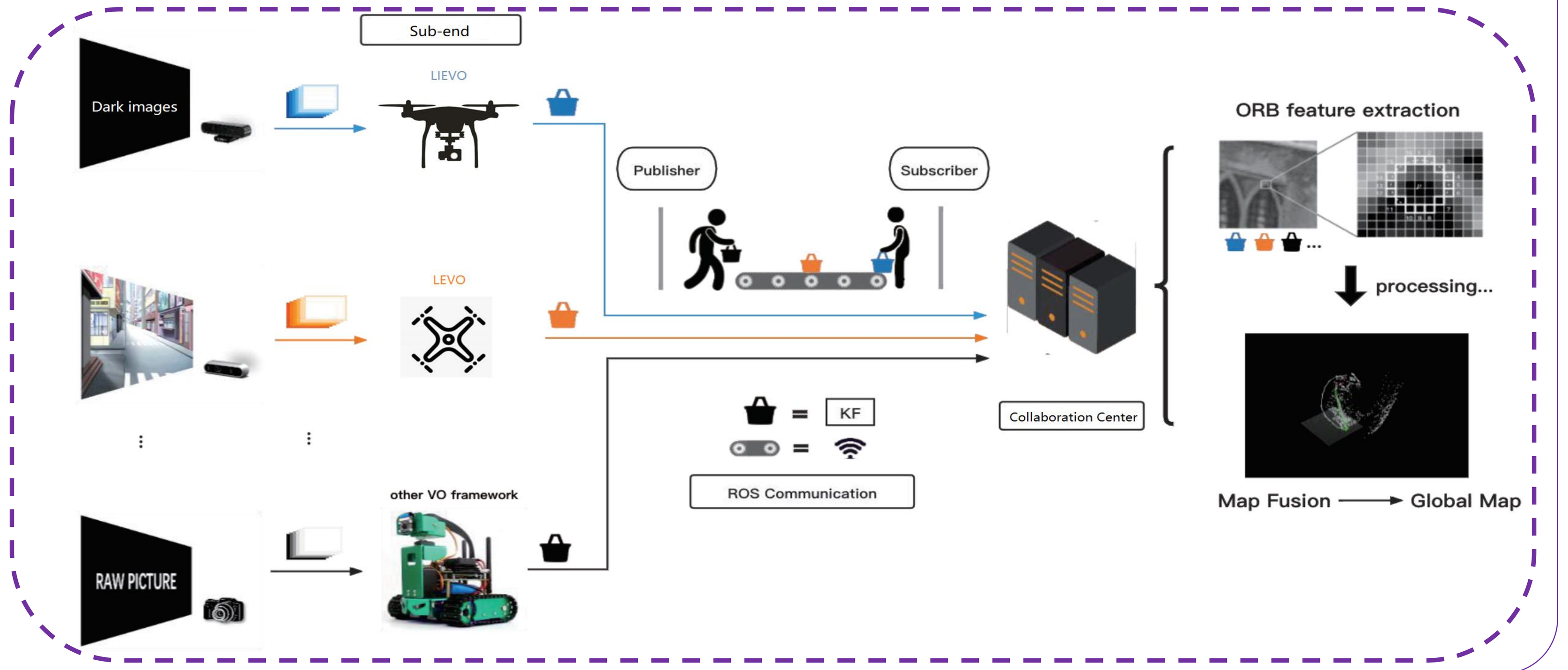
- **Low-level illumination edge-based visual odometry (LIEVO):** We extract edge features from the images and then perform the localization and mapping by feature matching. The part of edge detection in a dark environment uses a deep learning approach.



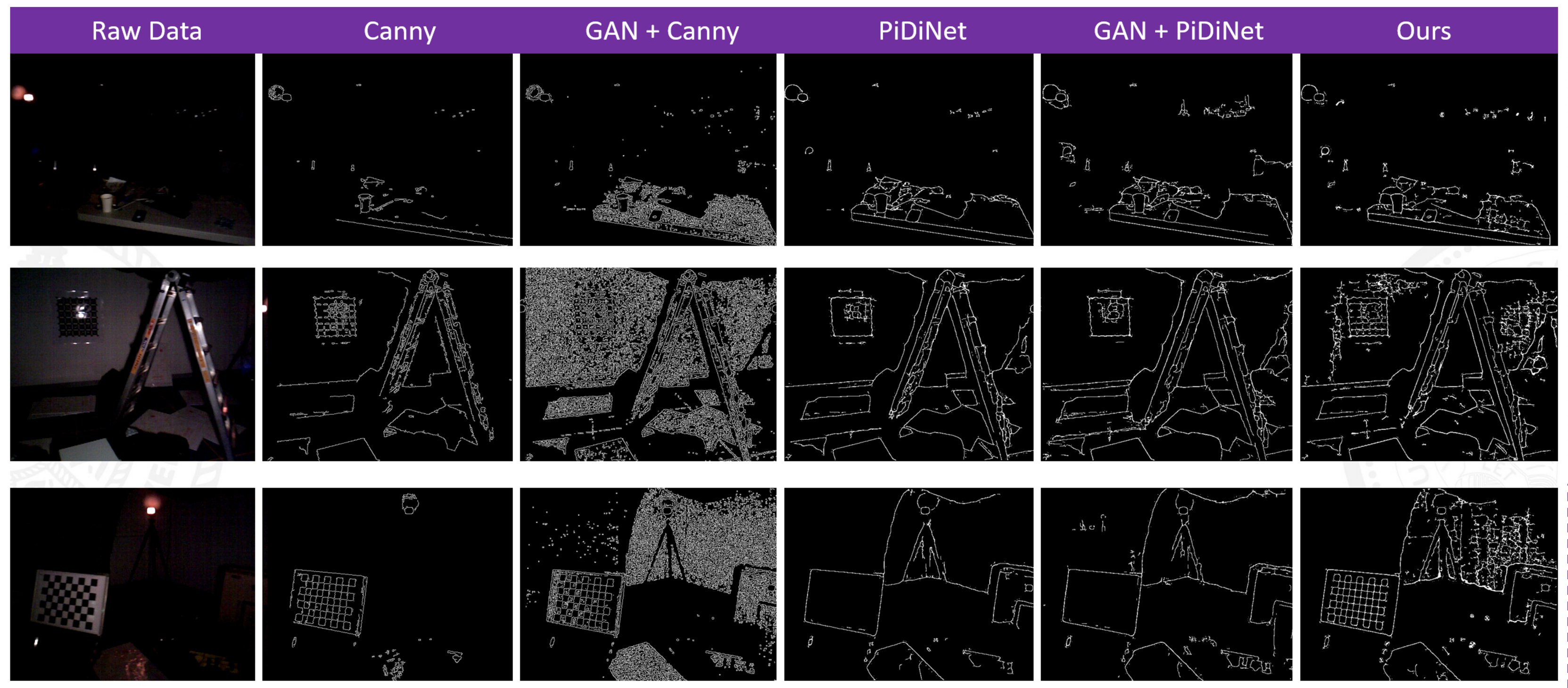
- **Low-lighting-edge network (LieNet):** We use PiDiNet[1] as a backbone and weakly supervised edge detection method by using dark-bright image pair for training. ED-bright and ED-dark indicates the edge detector respectively.



- **Multi-robot collaborative method.** In uneven illumination scenarios, the LIEVO algorithm is deployed using a powerful NVIDIA Xavier-based drone for low-light environments, while the LEVO algorithm is deployed using a lightweight Raspberry Pi-based drone for normal-brightness environments. The collaboration center is a server with higher performance, which is mainly used to run global optimization and map fusion.



RESULT



- **LIEVO extracts edge features in a dark environment.** From the comparison experimental figure, it can be intuitively seen that our method can extract edge features more accuracy and sophistication in the dark environment.

Sequence	Canny	PiDiNet	GAN + Canny	GAN + PidiNet	Ours
fr1/desk	0.1725	0.1903	0.1555	0.2566	**0.0522**
fr1/rpy	0.0800	0.1101	0.0485	0.0511	**0.0415**
fr1/teddy	0.0942	0.2325	0.2398	0.3612	**0.0753**
fr1/xyz	0.0635	0.0768	0.1005	0.1236	**0.0551**
fr2/coke	0.4662	0.4769	0.4689	0.4736	**0.4261**

- **LIEVO RMSE Accuracy:** The absolute trajectory error (ATE) was taken as the positional accuracy. It can be seen that our method has the best accuracy in the TUM dataset.

Sequence	Algorithm	Sub-end 1	Sub-end 2	Center
TUM[1](1, 2)	UI-SLAM	**0.2673**	**0.1219**	**0.2562**
	CCMSLAM	0.4192	0.7028	0.6681
TUM[2](1, 2)	UI-SLAM	0.3122	0.1411	0.2734
	CCMSLAM	**0.9023**	**0.6289**	**0.6799**
TUM[3](1, 2)	UI-SLAM	**0.1324**	**0.1886**	**0.1462**
	CCMSLAM	/	/	/
TUM[4](1, 2)	UI-SLAM	**0.1352**	**0.2525**	**0.2207**
	CCMSLAM	/	/	/
TUM[5](1, 2)	UI-SLAM	**0.0435**	**0.0421**	**0.0431**
	CCMSLAM	0.0499	0.1667	0.0996

- **Collaboration framework Evaluation:** Our method is significantly improved compared to the CCMSLAM[2]. As for the collaboration center, it achieved up to 45.98% improvement in collaboration accuracy under the uneven illumination scenarios.

CONCLUSIONS

In this paper, the idea of achieving high accuracy SLAM function under uneven lighting scenes was proposed by LIEVO vision odometry for low illumination environments and heterogeneous multi-robot collaboration framework for more lightweight and efficiency. From the experimental results, it can be seen that the problem of the poor localization accuracy under the uneven illumination has been well solved.

REFERENCES

[1] Su Z, Liu W, Yu Z, et al. Pixel difference networks for efficient edge detection[C]//Proceedings of the IEEE/CVF International Conference on Computer Vision. 2021: 5117-5127.

[2] Schmuck P, Chli M. CCM-SLAM: Robust and efficient centralized collaborative monocular simultaneous localization and mapping for robotic teams[J]. Journal of Field Robotics, 2019, 36(4): 763-781.