Small Object Change Detection for Small Obstacle Avoidance in Everyday Robot Navigation

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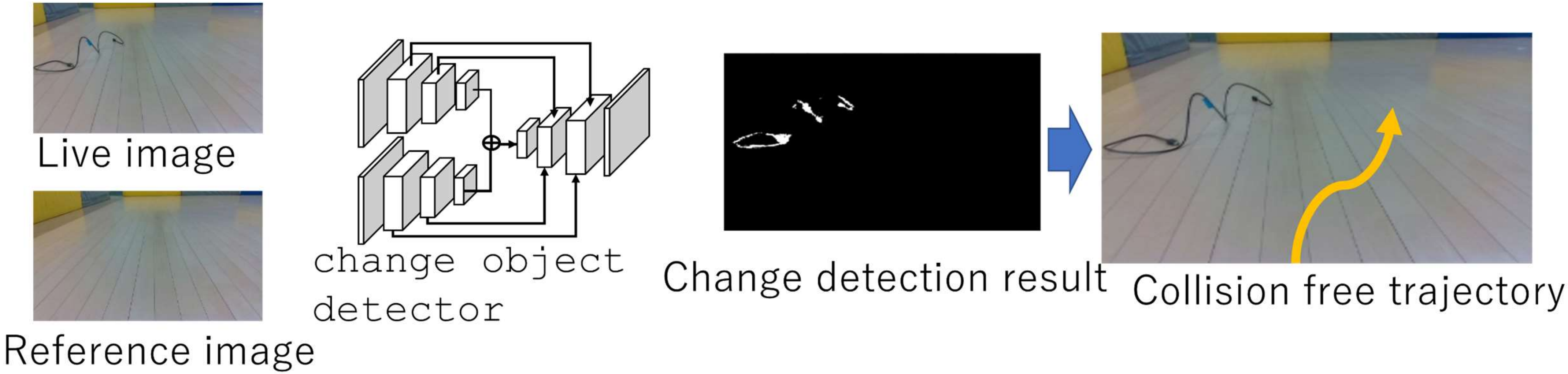
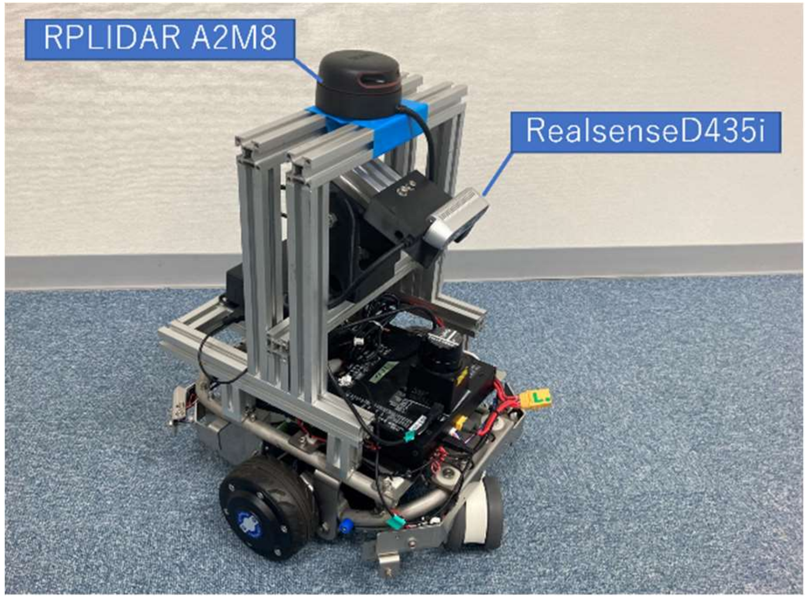
Goal: Image Change Detection for Small Obstacle Avoidance

- This paper considers the problem of small object change detection during everyday robot navigation and its application to small obstacle avoidance. Avoiding collisions with small objects (e.g., nails, cables, smartphones, glasses, handkerchiefs) is undoubtedly an important capability for an indoor mobile robot to avoid damaging itself and its surroundings. In this study, we consider everyday navigation scenarios, in which the robot may encounter unseen small objects in a familiar environment such as "convenience store," "flooring," and "office room".



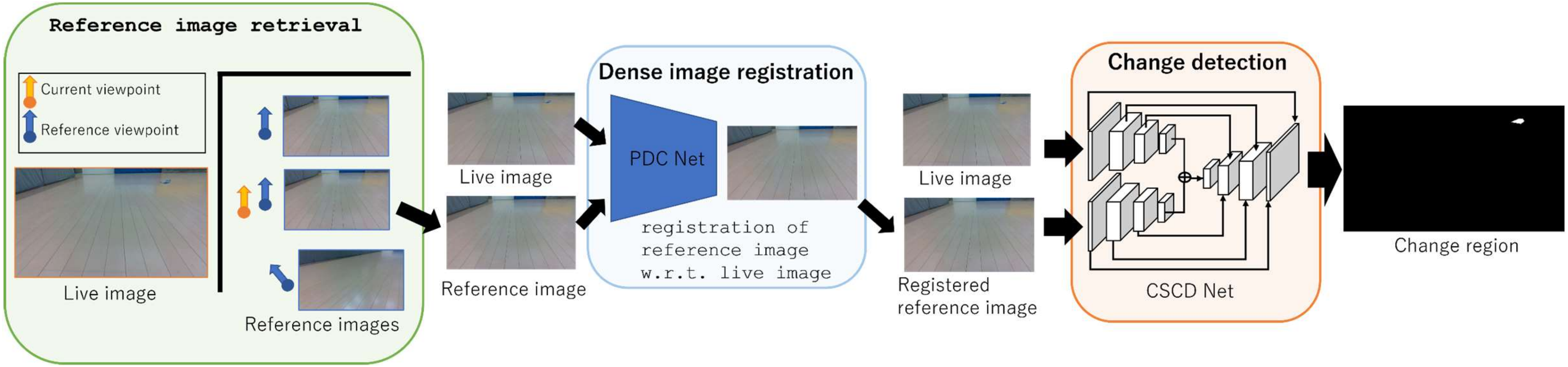
Challenge: Semantically Non-distinctive and Visually Small Objects

- Despite recent research progress in the field of object detection and change detection, the problem of detecting semantically non-distinctive and visually small objects is still a challenging problem.



Proposed method

- We developed a practical image processing pipeline by combining state-of-the-art techniques from image retrieval, image registration, and image change detection.



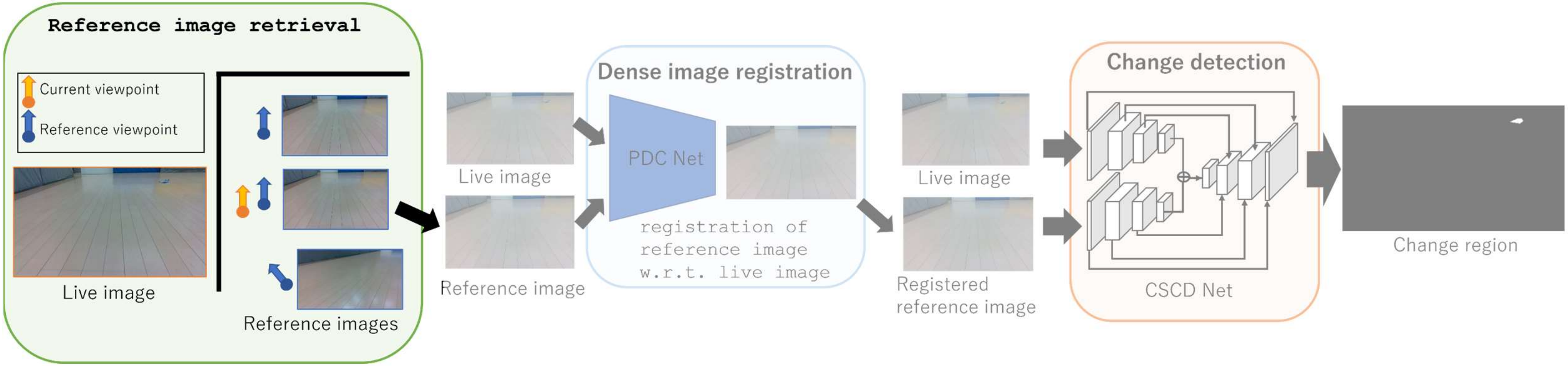
・LRF-SLAM based viewpoint estimation

・Pixel warping based dense image registration

・The state-of-the-art Siamese model for image change detection, CSCDNet [1]

[1] Sakurada, Ken, Mikiya Shibuya, and Weimin Wang. "Weakly supervised silhouette-based semantic scene change detection." *2020 IEEE International conference on robotics and automation (ICRA)*. IEEE, 2020
[15] Truong, Prune, et al. "Learning accurate dense correspondences and when to trust them." Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition. 2021.

Reference image retrieval



・A change detection algorithm requires a pairing of live and reference images tk3 as input. We developed an image retrieval system for aligning live images with the reference images.

・An input live image is paired with a reference image if its angle deviation from the live image is less than the threshold of 3.6 degree. If no such reference image exists, it is paired with the nearest neighbor viewpoint to the live image's viewpoint, without considering the angle information.

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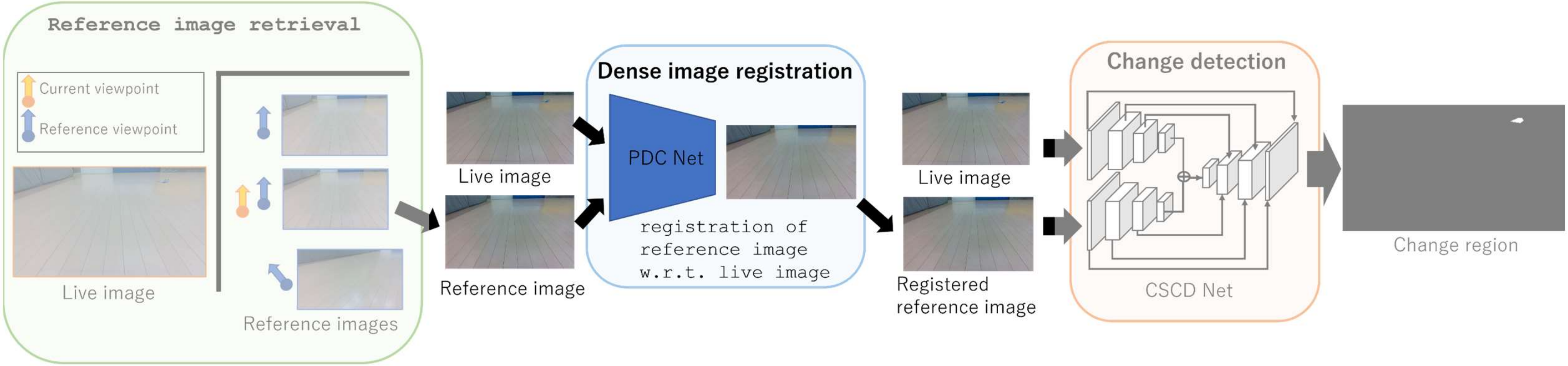
tanaka kanji; 01/10/2022

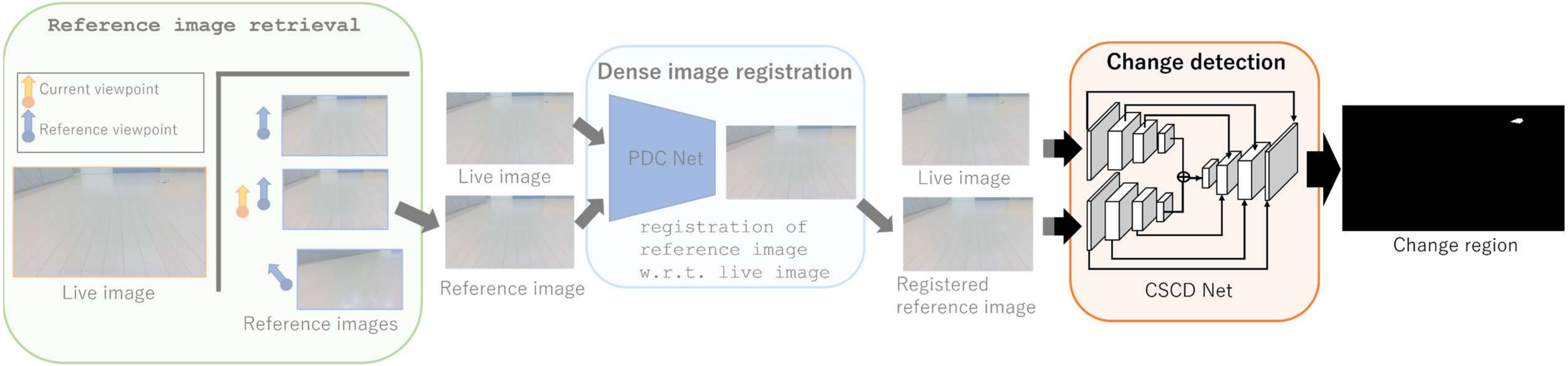
Dense image registration



・We further compensate for the viewpoint misalignment in LRF-SLAM by introducing an image warping technique. A warp is a 2D function, u(x, y), which maps a position (x, y) in the reference image to a position u = (x′, y′) in the live image.

・Compared with the conventional methods, the uncertainty of the prediction of the correspondence between pixels can be obtained at the same time, so that the prediction of pixels with high uncertainty can be unreliable.

Change detection

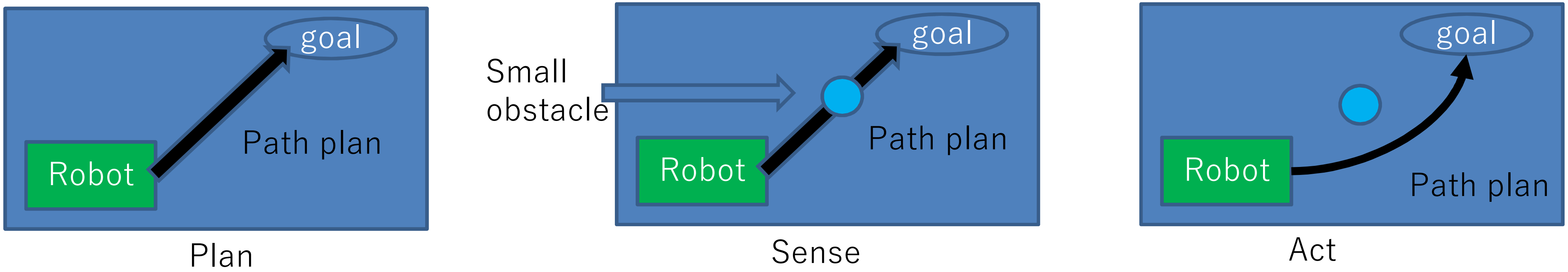


・The state-of-the-art Siamese model for image change detection, CSCDNet [1], is used as our base architecture. The network is initialized with the weight pre-trained on ImageNet [17]. The pixel-wise binary cross-entropy loss is used as loss function as in the original work of CSCDNet [1]. Adam optimizer [18] is used for the network training. Learning rate is 0.0001. The number of iterations is 20,000. The batch size is 32.

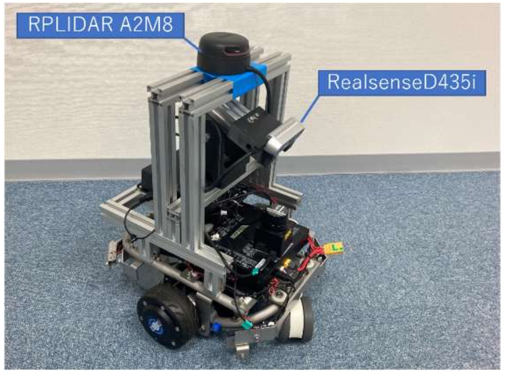
[1] Sakurada, Ken, Mikiya Shibuya, and Weimin Wang. "Weakly supervised silhouette-based semantic scene change detection." *2020 IEEE International conference on robotics and automation (ICRA)*. IEEE, 2020.
[17] Deng, Jia, et al. "Imagenet: A large-scale hierarchical image database." *2009 IEEE conference on computer vision and pattern recognition*. Ieee, 2009.
[18] Kingma, Diederik P., and Jimmy Ba. "Adam: A method for stochastic optimization." *arXiv preprint arXiv:1412.6980* (2014).

Plan-sense-act cycle

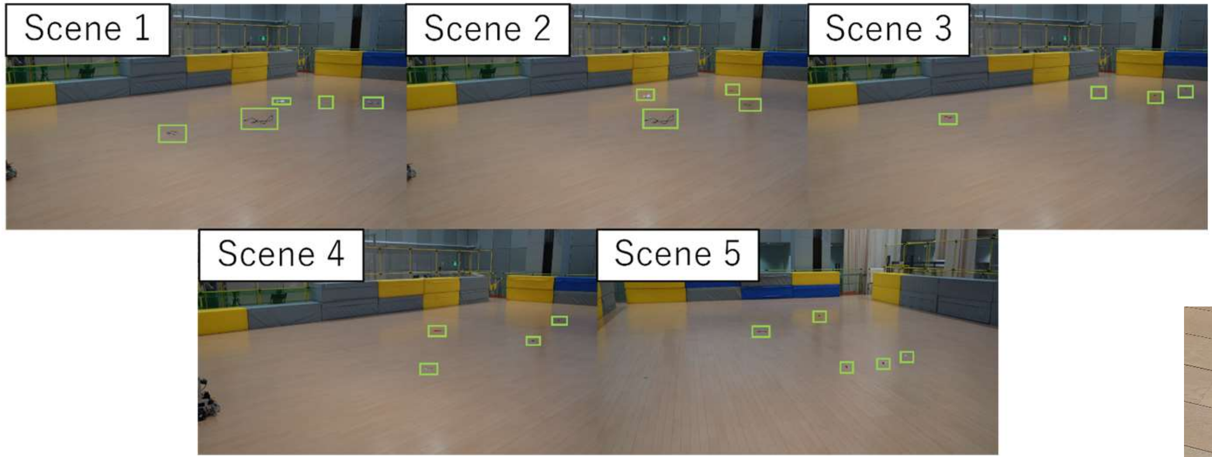
- The proposed image processing pipeline was implemented on a collision avoidance system for an indoor mobile robot. The collision avoidance system uses the traditional plan-sense-act cycle. In the planning phase, a static map of obstacles is used to find an collision-free route to the goal. The plan is updated in real time by feeding back the results of sense and action during navigation. Specifically, the map is updated by incorporating the information of new changing objects provided by the image processing pipeline into the obstacle map, assuming that the pose relationship between the floor surface and the camera coordinate system is a-priori known. The next best action is then generated via a shortest path algorithm on the updated map.

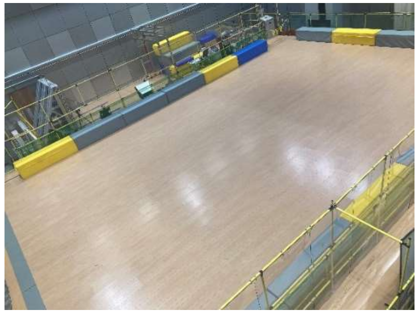


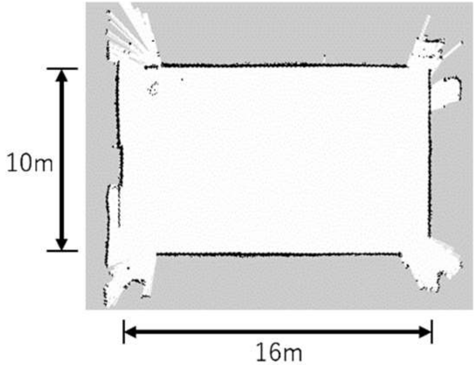
Experiment



- The proposed method was implemented on a real indoor mobile robot and verified experimentally.







Experimental setup

Parameters	Values
Learning rate of CSCD Net	0.0001
Training iteration of CSCD Net	20,000
Number of training images	184
Loss function of CSCD Net	Pixel wise binary cross entropy
GPU	NVIDIA GeForce RTX 3090
Camera	RealSenseD435i
ROS version	Noetic
Global planner	global_planner
Local planner	teb_local_planner

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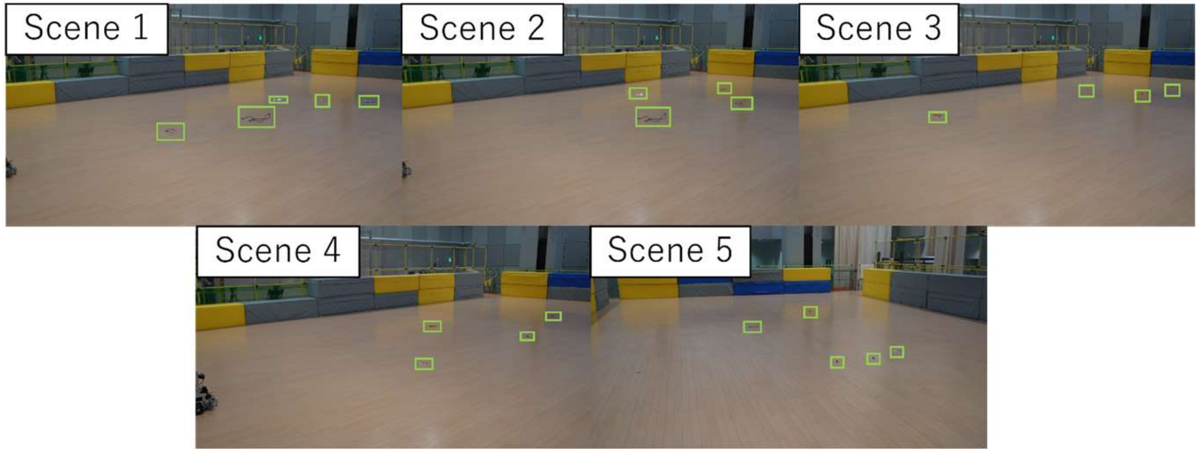
Experiment result

- The proposed method was successful for most small objects the robot encountered in the five different scenes.
- Bolt was the only object that the proposed framework failed to avoid a collision.



Scene ID	Depth Camera	Change Detection
1	× (smartphone)	✓
2	✓	✓
3	× (pliers, bolts)	× (bolts)
4	✓	✓
5	× (S-shaped hook)	✓

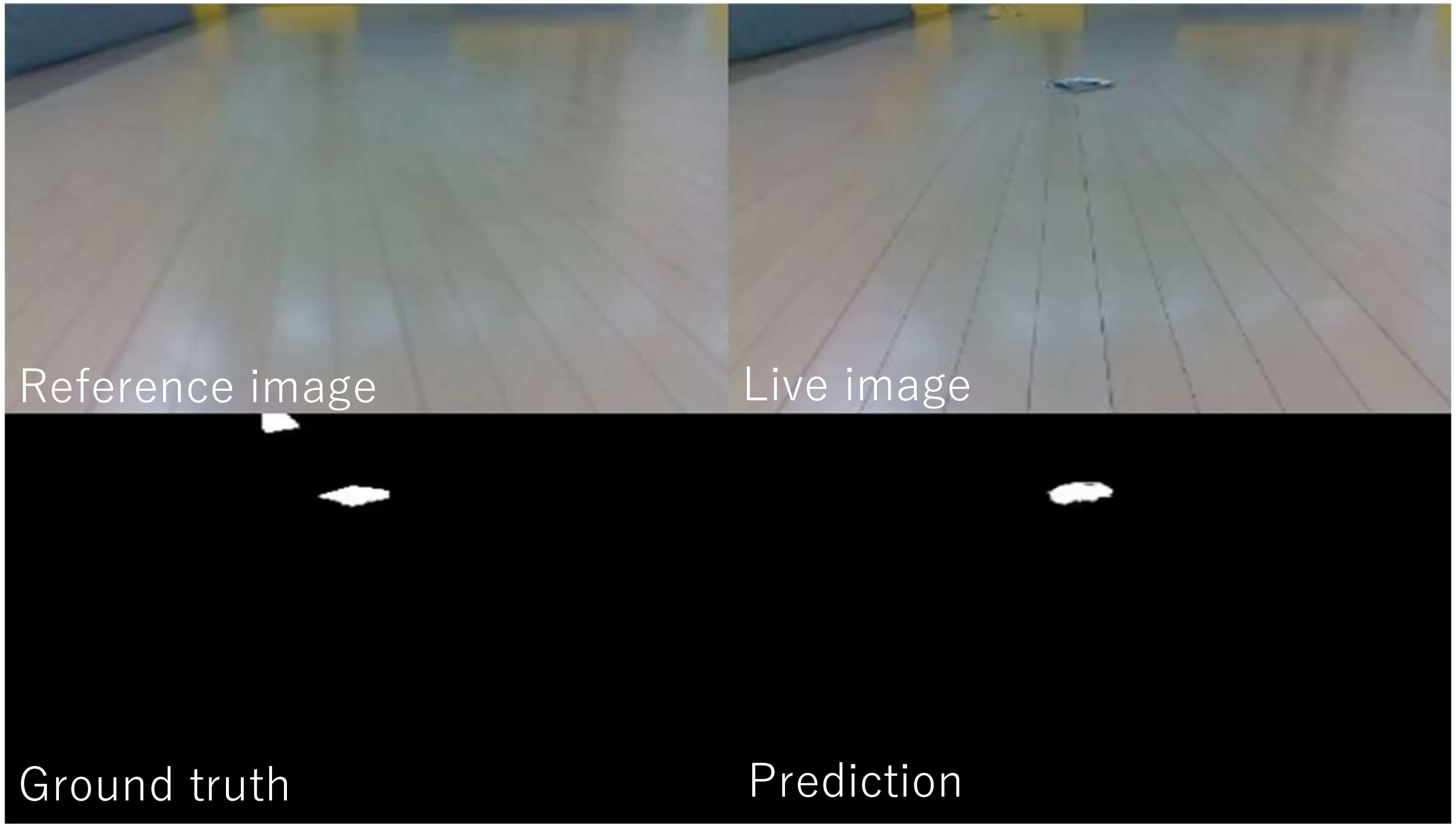
tk5

失敗例「ｘ」の小物体のみ「(smartphone)」のような物体名が明記されていますので、成功例「✓」の小物体についても物体名を明記しておくべきではないでしょうか？もし、この修正を反映されるのであれば、表の中に、object type という column を新設してもいいかもしれません。

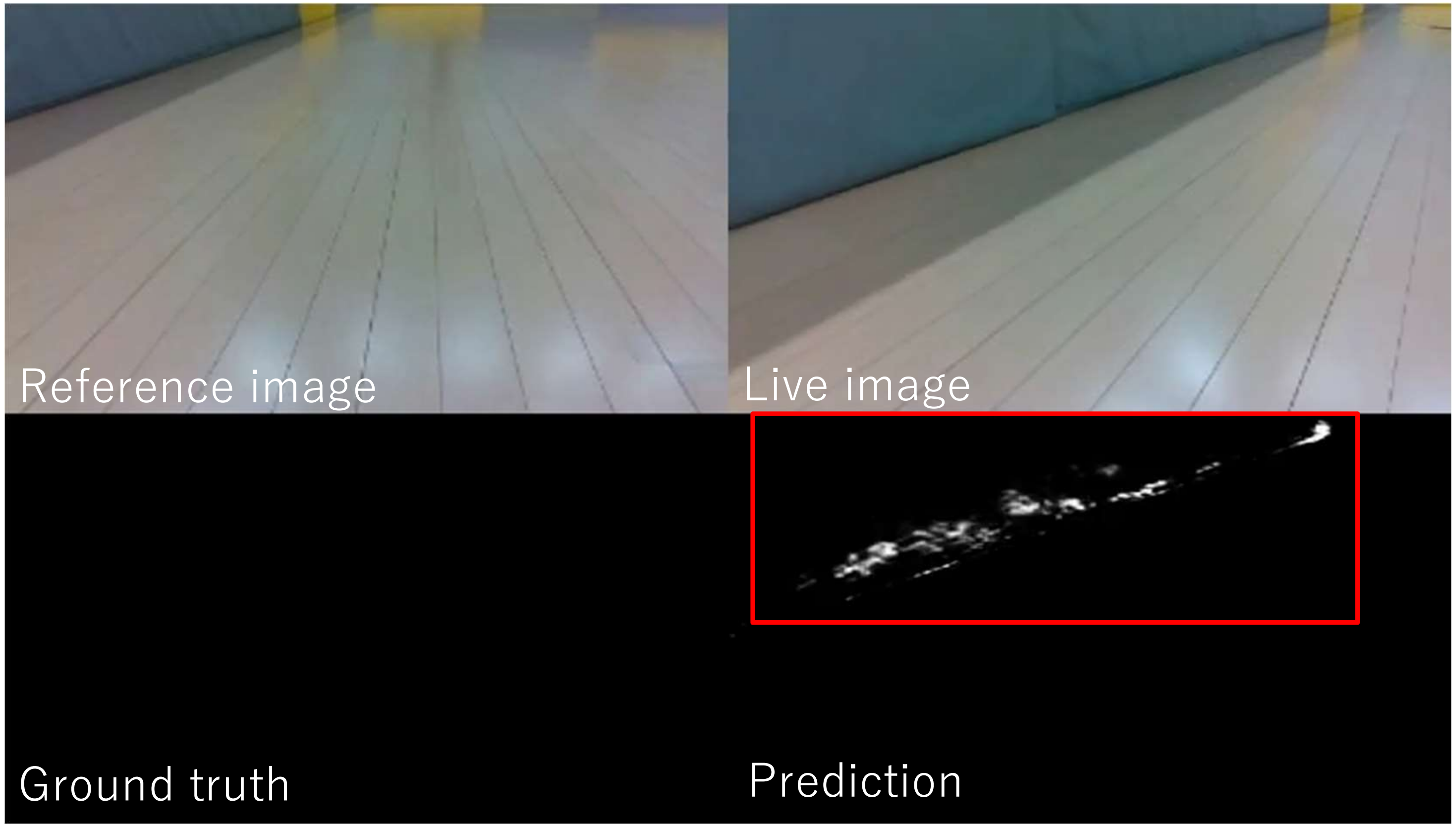
また、depth camera （センサ名）とchange detection（アルゴリズム名）が対になっていませんので、センサ名かアルゴリズム名のどちらかに統一したほうがいいように感じました。

tanaka kanji; 01/10/2022

Experimental result

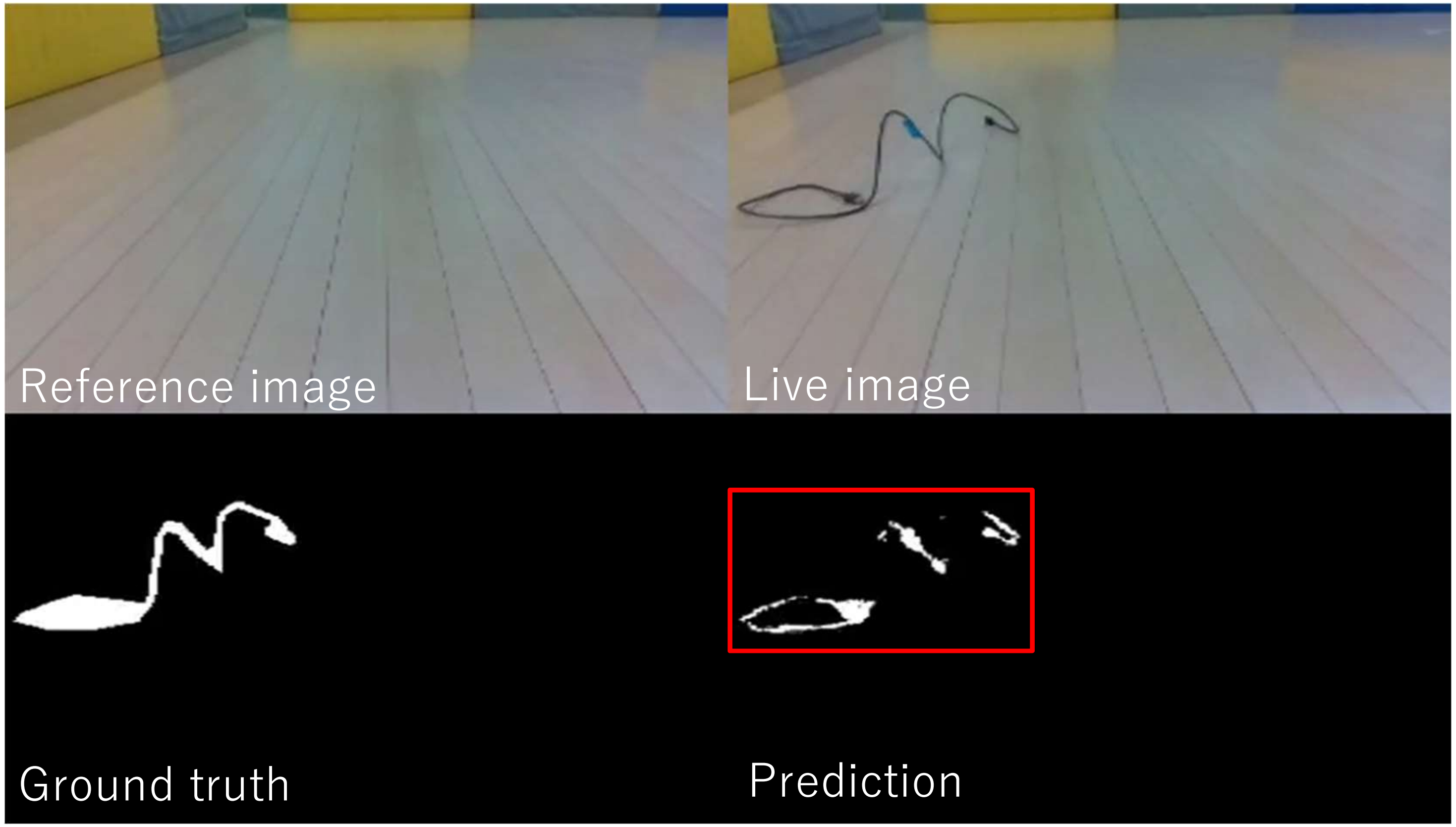


Experimental result



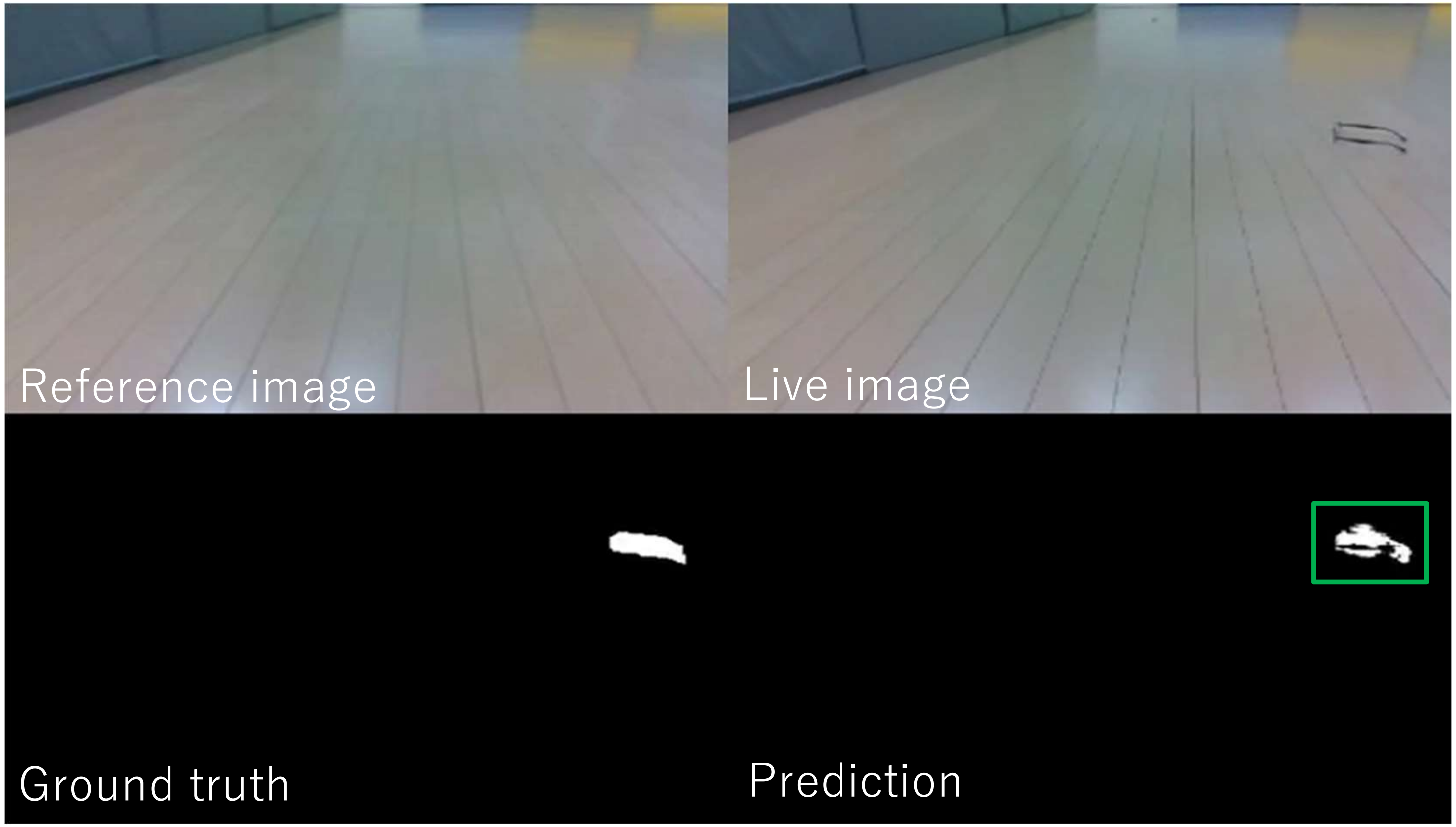
False positive caused by viewpoint change

Experimental result



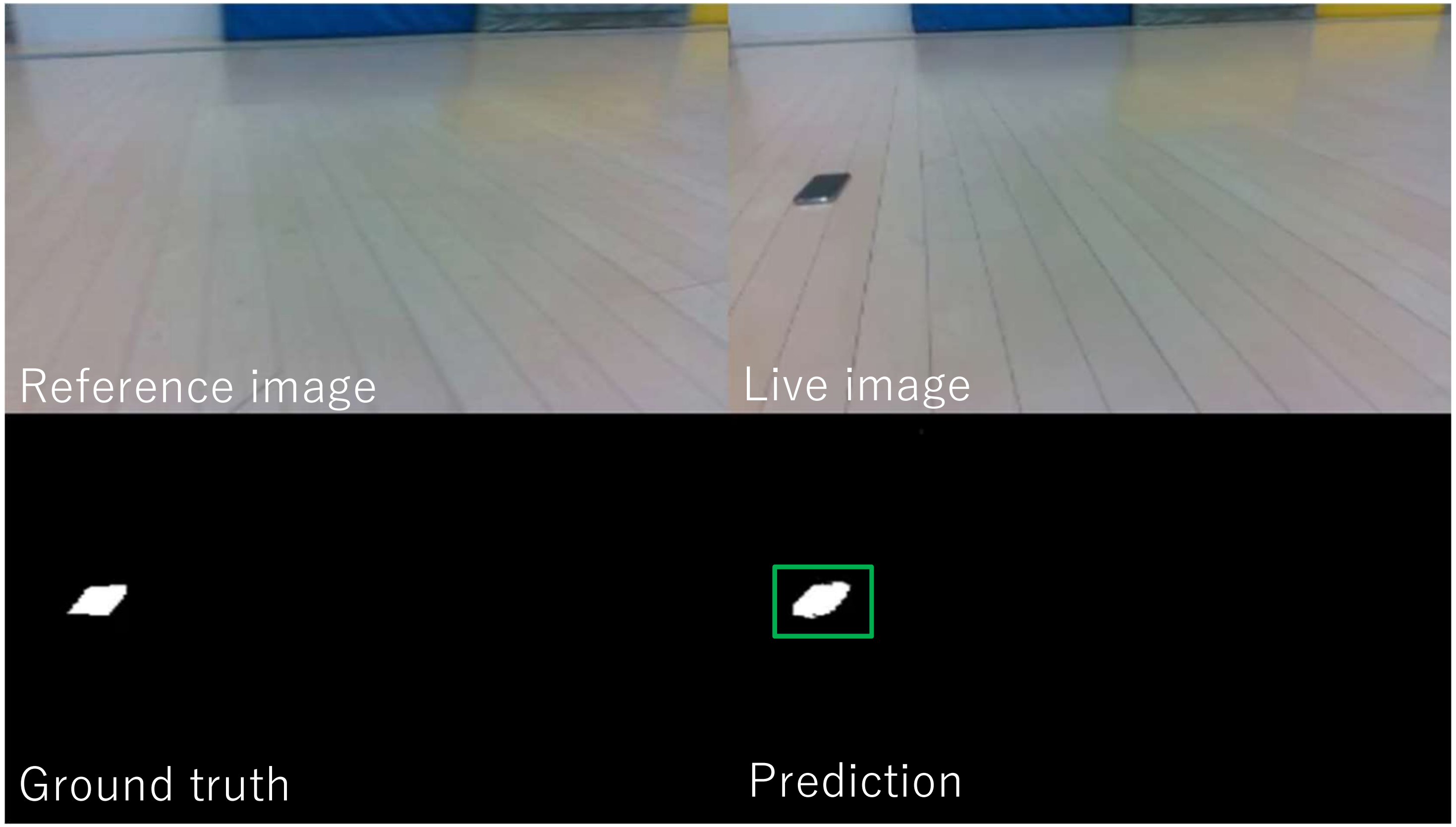
Missed detection by mistaking the cable for the pattern on the floor

Experimental result



Our method could detect thin object like glasses

Experimental result



Our method could detect thin object like smartphone

Conclusion

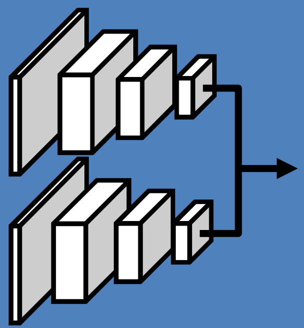
- Despite recent research progress in the field of object detection and change detection, the problem of detecting semantically non-distinctive and visually small objects is still a challenging problem.
- We developed a practical image processing pipeline by combining state-of-the-art techniques from image retrieval, image registration, and image change detection.
- We then integrated the image processing pipeline into a traditional plan-sense-act cycle to realize a reactive collision avoidance system.
- Experiments using a real mobile robot verified the effectiveness of the proposed approach.

Thank you for watching

変化領域検出

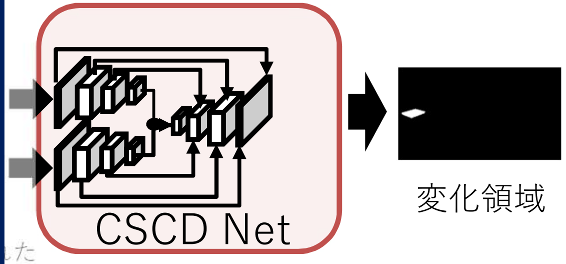
参照画像検索

Siamese ニューラルネットワーク



・2入力のニューラルネットワーク
・2本のエンコーダー部分の重みを共有
・変化検出のデファクトスタンダード

変化領域検出



概要

・ピクセルごとの変化検出を行うSiamese ニューラルネットワークのCSCD Net[6]を使用して変化領域を検出
・検出した変化領域を地図に登録して回避

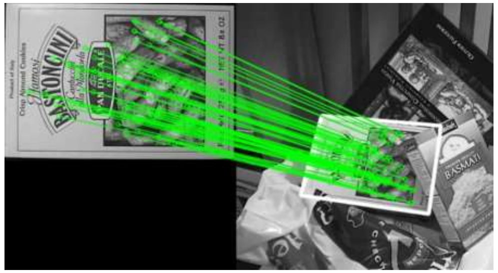
本実装のメリット

・Siameseベースのニューラルネットワークで、オプティカル フローの推定やステレオ マッチングに利用される相関層相関レイヤーを追加することにより微小な位置ずれに対処可能

[6] Sakurada, Ken, Mikiya Shibuya, and Weimin Wang. "Weakly supervised silhouette-based semantic scene change detection." *2020 IEEE International conference on robotics and automation (ICRA)*. IEEE, 2020.

他の画像変化検出手法とSiameseベース変化検出手法の比較

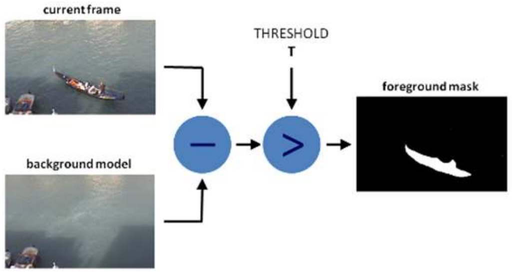
画像局所特徴マッチング
（例：SIFT特徴＋RANSACマッチング）



https://docs.opencv.org/3.4/d1/de0/tutorial_py_feature_homography.html

密な変化検出ができないため小物体検出には向かない

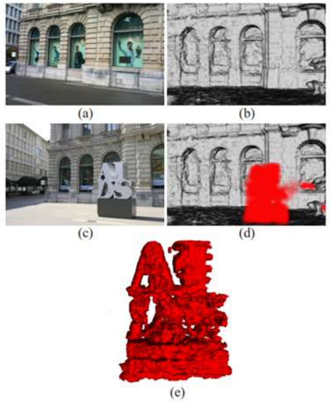
背景差分



https://docs.opencv.org/3.4/d1/dc5/tutorial_background_subtraction.html

視点変化が発生しやすいロボットの文脈での変化検出には向かない

再構築法
（例：3D再構築＋仮想視点画像）[7]



仮想画像によって小物体が消えてしまう可能性がある

Siameseベース変化検出手法であれば、、、

- ピクセル単位の変化検出が可能
- 視点変化の影響を受けづらい
- 小物体が消失する心配がない

[7] Taneja, Aparna, Luca Ballan, and Marc Pollefeys. "Image based detection of geometric changes in urban environments." 2011 International Conference on Computer Vision. IEEE, 2011.

Limitation of change detection

- Despite recent research progress in the field of object detection and change detection, the problem of detecting semantically non-distinctive and visually small objects is still a challenging problem.

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