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Comparative Study of Visual SLAM-Based Mobile Robot Localization Using Fiducial Markers

Jongwon Lee[1], Su Yeon Choi[1], David Hanley[2], and Timothy Bretl[1]

[1]Department of Aerospace Engineering, University of Illinois Urbana-Champaign, USA
[2]School of Informatics, University of Edinburgh, UK

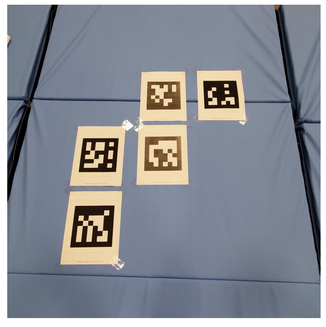
Introduction

- SLAM with fiducial markers—square-shaped planar artificial landmarks with a black-and-white grid pattern—has advantages such as:
  - Better accuracy over canonical approaches using visual feature
  - Less computational cost compared to hybrid approaches using both feature and marker detection without compromising accuracy
- This work presents a comparative study of three modes of fiducial marker-based SLAM, in terms of absolute trajectory error and runtime for the optimization process per frame:
  - **SLAM**: Estimate both pose and map from scratch
  - **SLAM with a prior map**: Estimate pose and map given a prior map
  - **Localization with a prior map**: Estimate pose only given a prior map

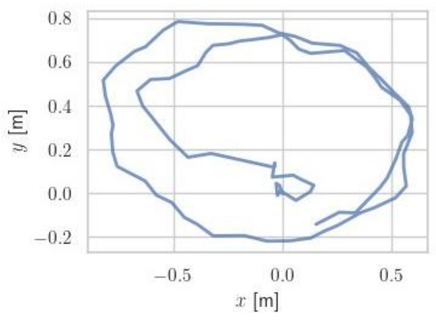
  * The quality of the prior map is critical for the last two modes; we investigate each method's tolerance to variations in prior map quality

Experiments

- We tested three modes over 7 sequences, 30 seconds each, with 1280x720 camera images at 30Hz, and Vicon MoCap ground truth within <10m trajectory
- **Where does the prior map come from?** The SLAM mode was employed on a preliminary sequence to create a prior map
- **How are the SLAM with a prior map and localization modes evaluated with respect to prior map quality?** We perturbed fiducial marker position in a prior map ($\delta\mathbf{p}$) and assessed mode tolerance to prior map quality



The data collection environment featuring five 36h11 AprilTags, each having side lengths of 0.2m



An example trajectory for experiments in simulation (sequence 4)

Results

1. Absolute trajectory error

sequence	SLAM [m]	SLAM with a Prior Map [m] $\delta\mathbf{p}$ [m]						Localization [m] $\delta\mathbf{p}$ [m]					
		0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.10	0.20	0.30	0.40	0.50
1	0.07	0.05	0.05	0.07	0.08	0.08	0.08	0.06	0.23	0.22	0.44	1.18	1.21
2	0.08	0.07	0.07	0.08	0.04	0.10	0.10	0.08	0.25	0.31	0.60	1.58	1.69
3	0.08	0.08	0.08	0.10	0.10	0.09	0.10	0.10	0.21	0.28	0.45	1.28	1.34
4	0.14	0.14	0.14	0.15	0.15	0.14	0.14	0.15	0.45	0.43	0.58	0.96	2.35
5	0.13	0.13	0.13	0.13	0.11	0.13	0.13	0.14	0.40	0.52	0.44	1.28	2.43
6	0.10	0.08	0.09	0.10	0.10	0.10	0.10	0.13	0.39	0.42	1.44	2.04	2.50
7	0.12	0.12	0.11	0.12	0.12	0.11	0.11	0.11	0.49	0.42	0.61	1.78	1.54
average	0.10	0.10	0.10	0.11	0.10	0.11	0.11	0.11	0.35	0.37	0.65	1.44	1.87

- Without perturbation (i.e., $\delta\mathbf{p} = 0.00$), all three modes yield results showing differences within a few centimeters
- With perturbation, the SLAM with a prior map mode maintains results within a few centimeters, while the localization mode increases to tens of centimeters even with the smallest perturbation (i.e., $\delta\mathbf{p} = 0.10$)

2. Runtime for the optimization process per frame

sequence	SLAM [ms]	SLAM with a Prior Map [ms] $\delta\mathbf{p}$ [m]						Localization [ms] $\delta\mathbf{p}$ [m]					
		0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.10	0.20	0.30	0.40	0.50
1	5.07	5.26	5.79	5.00	5.75	6.23	6.42	3.05	3.53	3.90	4.56	5.33	6.06
2	4.92	5.81	5.15	5.92	6.06	5.70	6.15	4.69	5.28	5.09	6.26	7.52	8.35
3	5.31	6.43	5.71	5.50	5.20	6.30	6.11	4.60	4.33	4.71	4.90	6.20	7.12
4	5.73	6.05	5.91	6.77	6.35	6.63	6.66	4.80	4.49	7.66	4.99	6.29	7.60
5	6.23	6.19	7.34	6.27	7.42	7.02	6.81	5.81	6.33	6.83	8.06	8.61	9.76
6	6.08	6.56	4.64	6.69	6.61	7.46	6.30	4.78	7.44	6.15	7.43	9.92	9.75
7	7.95	8.80	9.23	7.45	8.06	9.11	7.94	5.22	6.66	8.13	9.19	8.47	8.99
average	5.90	6.44	6.25	6.23	6.49	6.92	6.63	4.71	5.44	6.07	6.48	7.48	8.23

- The SLAM with a prior map mode shows a consistent and slightly longer (~20%) runtime compared to the SLAM mode in response to perturbation
- The localization mode shows shorter runtime (~20%) than the SLAM mode, while showing a rise in runtime along with the increase in perturbation

Conclusions

- If an accurate prior map exists, use localization mode

Acknowledgement

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