Semester Project

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Map Fusion for Collaborative UAV SLAM

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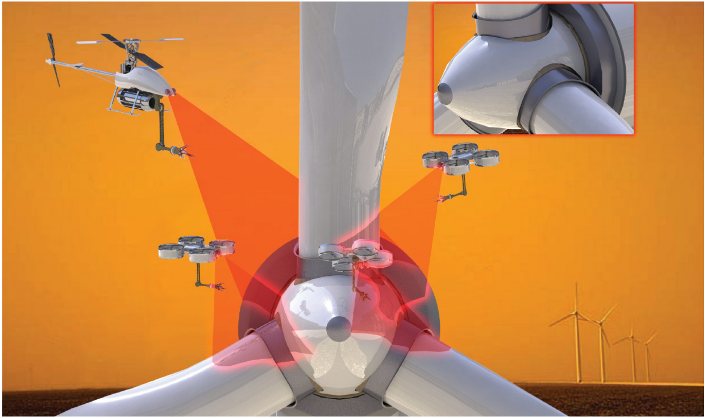
ETH zürich · V4RL VISION FOR ROBOTICS LAB · Autonomous Systems Lab

Contents

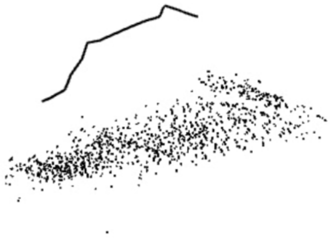
Acronyms

SLAM	Simultaneous Localisation and Mapping.
UAV	Unmanned Aerial Vehicle.
KF	KeyFrame.
KFM	KeyFrame Match.
BA	Bundle Adjustment.
PGO	Pose Graph Optimization.
LM	Levenberg-Marquardt.
DL	Powell's dog leg.

Introduction



Introduction



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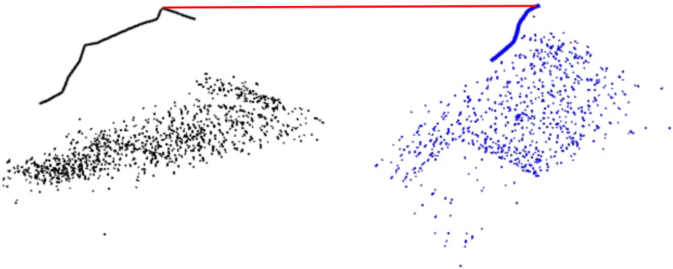

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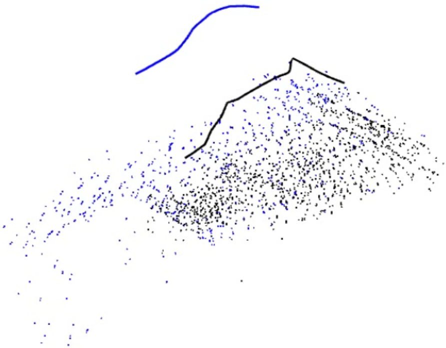

Introduction - What is a KeyFrame Match (KFM)?

KeyFrames (KFs): The most “representative” poses

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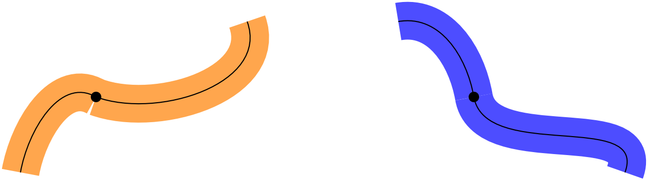
KeyFrames (KFs): The most “representative” poses

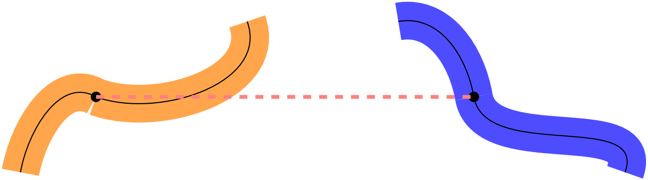
Two clients each with own landmarks and KeyFrames (KFs)



Introduction - What is a KeyFrame Match (KFM)?

KeyFrames (KFs): The most “representative” poses

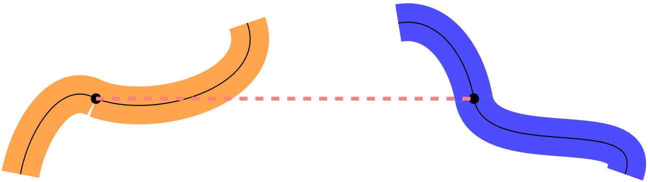
KeyFrame Match (KFM): Two KeyFrames (KFs) observing the same location



Introduction - What is a KeyFrame Match (KFM)?

KeyFrames (KFs): The most “representative” poses

KeyFrame Match (KFM): Two KeyFrames (KFs) observing the same location → Can obtain transformation

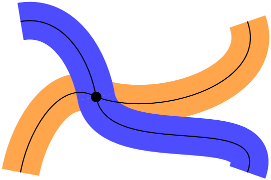


Introduction - What is a KeyFrame Match (KFM)?

KeyFrames (KFs): The most “representative” poses

KeyFrame Match (KFM): Two KeyFrames (KFs) observing the same location

With the transformation → maps can be aligned

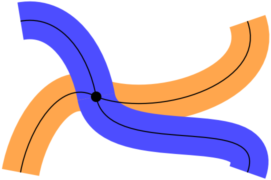


Introduction - What is a KeyFrame Match (KFM)?

KeyFrames (KFs): The most "representative" poses

A KeyFrame Match (KFM) contains:

- Two KeyFrames (KFs) (One per map)
- The transformation ($T \in \mathrm{Sim}(3)$) between them



Motivation

- A multi agent SLAM system based on ORB-SLAM2 should be extended

[Mur-Artal and Tardos, 2016]

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- So far, as soon as a KeyFrame Match (KFM) was detected, maps were merged

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- Using multiple KFMs to guarantee no false map merging

[Mur-Artal and Tardos, 2016]

Motivation

- A multi agent SLAM system based on ORB-SLAM2 should be extended
- So far, as soon as a KeyFrame Match (KFM) was detected, maps were merged
- Using multiple KFMs to guarantee no false map merging
- Using multiple KFMs to obtain an optimal map alignment

[Mur-Artal and Tardos, 2016]

Map merging - Old approach

Old approach:

- As soon as a KFM was detected, maps were merged

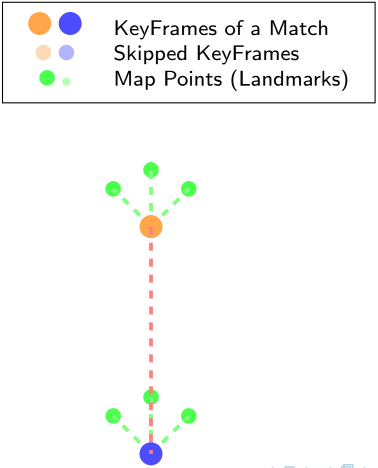
Map merging - New approach

Find $n(=3)$ KeyFrame Matches (KFMs)

KeyFrames of a Match
Skipped KeyFrames
Map Points (Landmarks)

Map merging - New approach

Find $n(=3)$ KeyFrame Matches (KFMs),
Skip $m(=5)$ KeyFrames (KFs)



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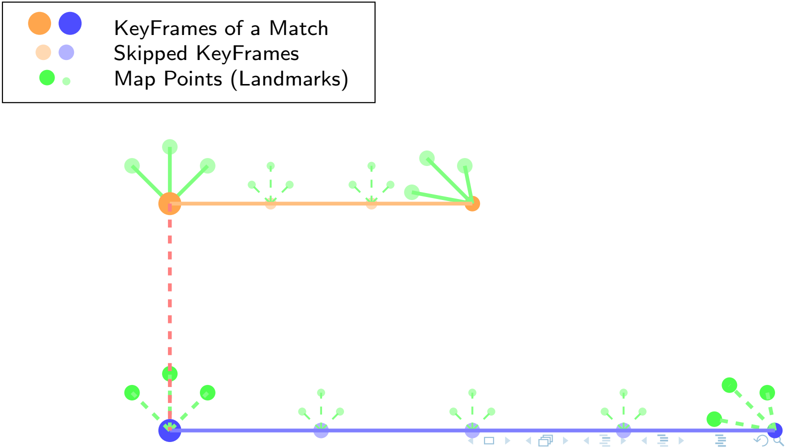

Map merging - New approach

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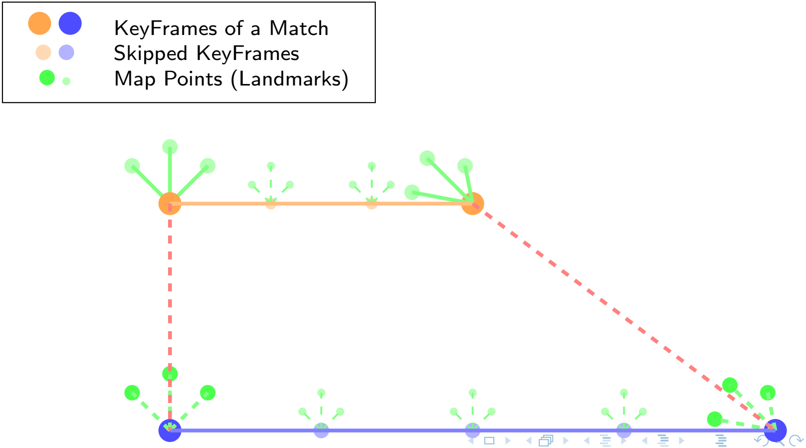
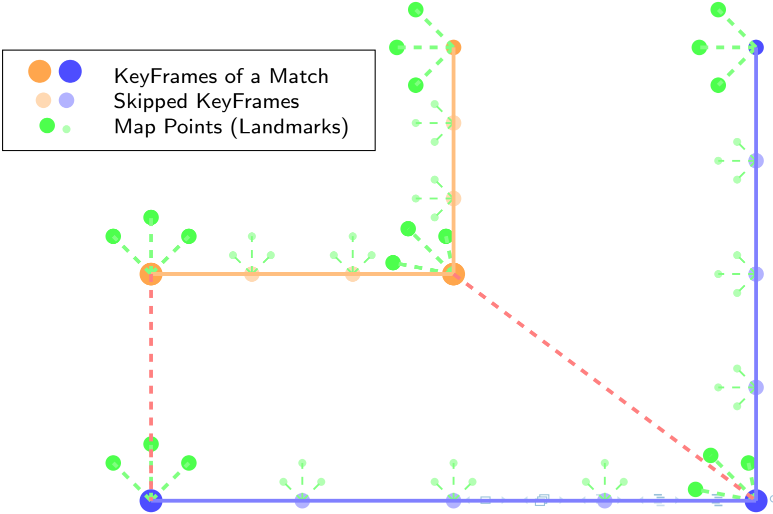


Map merging - New approach

Find $n(=3)$ KeyFrame Matches (KFMs), Skip $m(=5)$ KFs



Map merging - New approach

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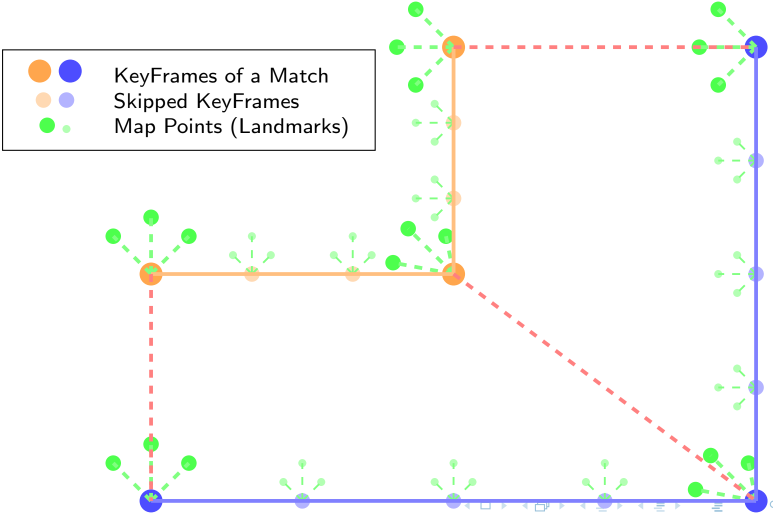

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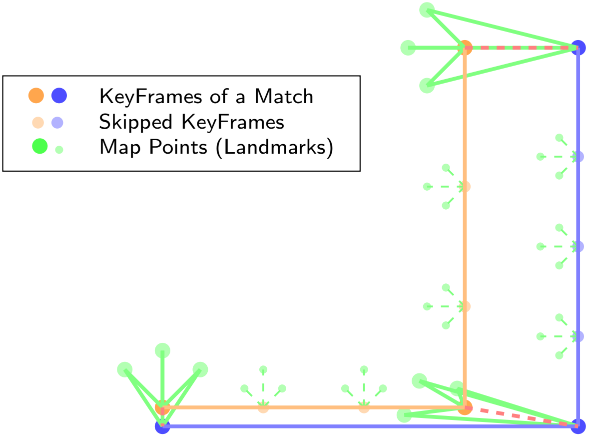
Merge the two maps and fuse map points



Map merging - Results - skipping of KeyFrame (KF)

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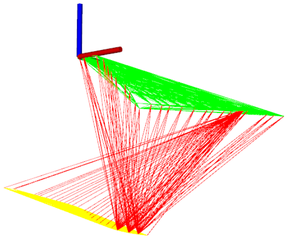
Co-visibility graph

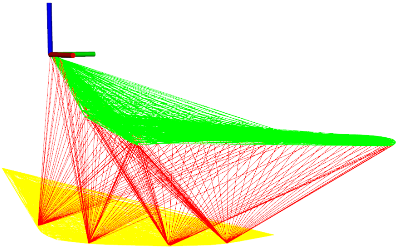
Connections/Edges between KeyFrames (KFs) which observe the same map points (landmarks)

Map merging - Results - skipping of KF

green: Covisibility graph of first map
yellow: Covisibility graph of second map
red: Covisibility between the KFMs

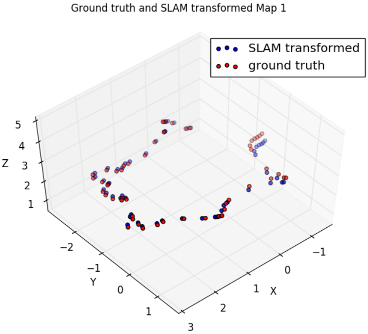


(a) 1 KF skipped after a KFM was found

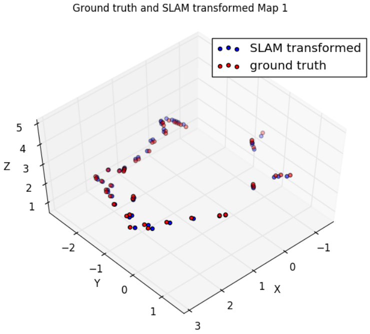


(b) 10 KF skipped after a KFM was found

Map merging - Results - Reduction of drift



(a) original approach



(b) new approach

Reduction of the error from rmse $= 0.13\text{m}$ to rmse $= 0.10\text{m}$

Culling - Remove redundant KF

Motivation

Perform KeyFrame (KF) culling to remove redundant information as bundle adjustment complexity grows with the number of KFs
[Mur-Artal et al., 2015]

Culling - Remove redundant KF

- Remove redundant KFs before map merging

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- Performs culling for every KFM separately

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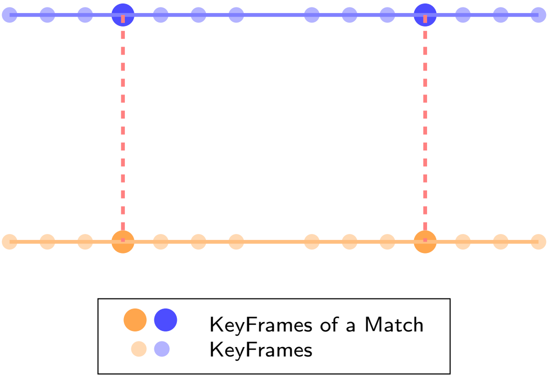
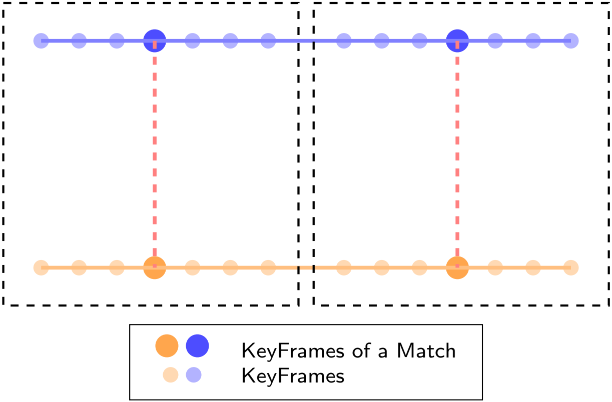


Culling - Remove redundant KF

- Remove redundant KFs before map merging
- Performs culling for every KFM separately



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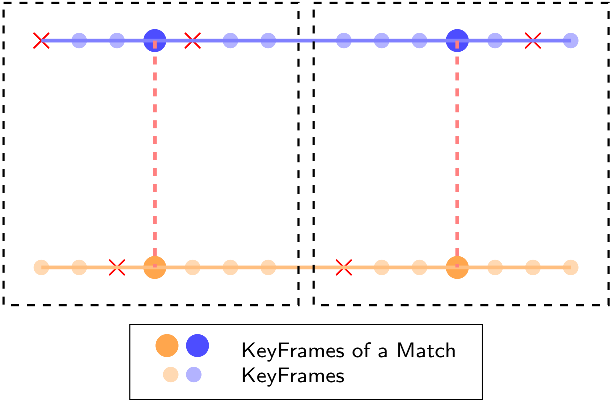

Culling - Results

Culling removes $\approx 13\%$ of the KeyFrames (KFs)

Pose Graph Optimization (PGO)
Bundle Adjustment (BA)

Culling - Results

Culling removes $\approx 13\%$ of the KeyFrames (KFs)

Culling	# KFMs	# KFs skipped	PGO [ms]	BA [ms]
No	10	10	532.28	3659.48
Yes	10	10	178.83	1098.37

Table: Time measurements of PGO and BA without and with culling.

Pose Graph Optimization (PGO)
Bundle Adjustment (BA)

Culling - Results

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Culling	# KFMs	# KFs skipped	PGO [ms]	BA [ms]
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Table: Time measurements of PGO and BA without and with culling.

Performance increases significantly when culling is enabled

Pose Graph Optimization (PGO)
Bundle Adjustment (BA)

Culling - Results

Culling	# KFMs	# KFs skipped	*rmse* [m]
No	1	0	0.1311
Yes	1	0	0.2187
No	10	10	0.0961
Yes	10	10	0.0965

Table: *rmse* without and with culling.

Culling - Results

Culling	# KFMs	# KFs skipped	*rmse* [m]
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No	10	10	0.0961
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Table: *rmse* without and with culling.

Accuracy gets worse if not enough information is available.
No problem with multiple KeyFrame Matches (KFMs).

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Optimization - Idea

Considerable computational benefits can be gained by substituting the Levenberg-Marquardt (LM) algorithm in the implementation of Bundle Adjustment (BA) with a variant of Powell's dog leg (DL) non-linear least squares technique [Lourakis and Argyros, 2005]

Optimization - Idea

Considerable computational benefits can be gained by substituting the Levenberg-Marquardt (LM) algorithm in the implementation of Bundle Adjustment (BA) with a variant of Powell's dog leg (DL) non-linear least squares technique [Lourakis and Argyros, 2005]

DL optimizer handles trust region differently

Optimization - Approach

- Tried Pose Graph Optimization (PGO) and Bundle Adjustment (BA) with the Powell's dog leg (DL) optimizer

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- PGO: Slightly worse timing using the DL optimizer

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- BA: Better timing using the DL optimizer

Optimization - Approach

- Tried Pose Graph Optimization (PGO) and Bundle Adjustment (BA) with the Powell's dog leg (DL) optimizer

- PGO: Slightly worse timing using the DL optimizer
- BA: Better timing using the DL optimizer

Conclusion

LM optimizer for PGO and DL optimizer for BA

Optimization - Results

Opt.	# KFMs	# KFs skipped	PGO [ms]	BA [ms]
LM/LM	10	10	178.83	1098.37
LM/DL	10	10	178.70	383.54

Table: Time measurements of LM and DL optimizer.

Pose Graph Optimization (PGO)
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Optimization - Results

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LM/LM	10	10	178.83	1098.37
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Table: Time measurements of LM and DL optimizer.

Accuracy stays the same while the performance is increased

Pose Graph Optimization (PGO)
Bundle Adjustment (BA)

Conclusion

- Multiple KFMs approach increases accuracy

Conclusion

- Multiple KFMs approach increases accuracy
- Skipping of KFs spreads KFMs over a bigger area

Conclusion

Higher accuracy

The use of KFMs from a bigger area serves PGO and BA with more information $\rightarrow$ higher accuracy

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- Culling removes redundant KFs $\rightarrow$ improved timing

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The use of KFMs from a bigger area serves PGO and BA with more information $\rightarrow$ higher accuracy

- Culling removes redundant KFs $\rightarrow$ improved timing
- Using DL optimizer for the BA also improves timing

Conclusion

Higher accuracy

The use of KFMs from a bigger area serves PGO and BA with more information $\rightarrow$ higher accuracy

Better timing

Culling and the use of the DL optimizer improves timing

Outlook & Limitation

Outlook:

- Heuristic for best map alignment
- Extend area for KF culling

Limitation:

- # of KFMs and # of skips depends on data set

Outlook & Limitation

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Q&A

References

Lourakis, M. I. A. and Argyros, A. A. (2005).
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ORB-SLAM2: an Open-Source SLAM System for Monocular, Stereo and RGB-D Cameras.