A Comprehensive Review of Extrinsic Calibration Methods for Multi Robot systems

Bruno Silva - *Author*
Miguel Oliveira - *Advisor*
Eurico Pedrosa - *Advisor*

University of Aveiro
PhD. in Mechanical Engineering.

January 6, 2025

Table of contents

Introduction

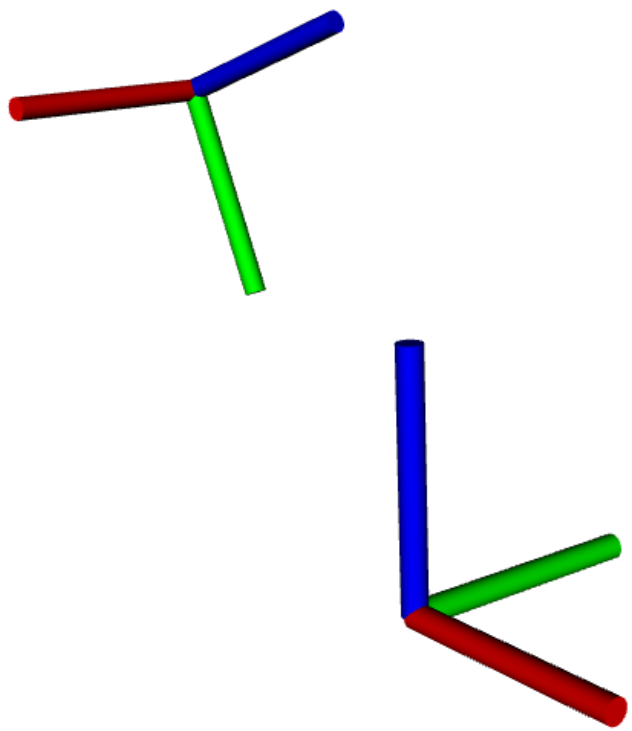
Choosing the thematic

Multi-Robot Calibration

Dynamic Robot Path Planning

Key Concepts
Math Concepts

Geometric Transformation



Key Concepts
Robot Calibration

Intrinsic Calibration

Extrinsic Calibration

Key Concepts
Robot Calibration

Intrinsic Calibration

Extrinsic Calibration

Key Concepts
Robot Calibration

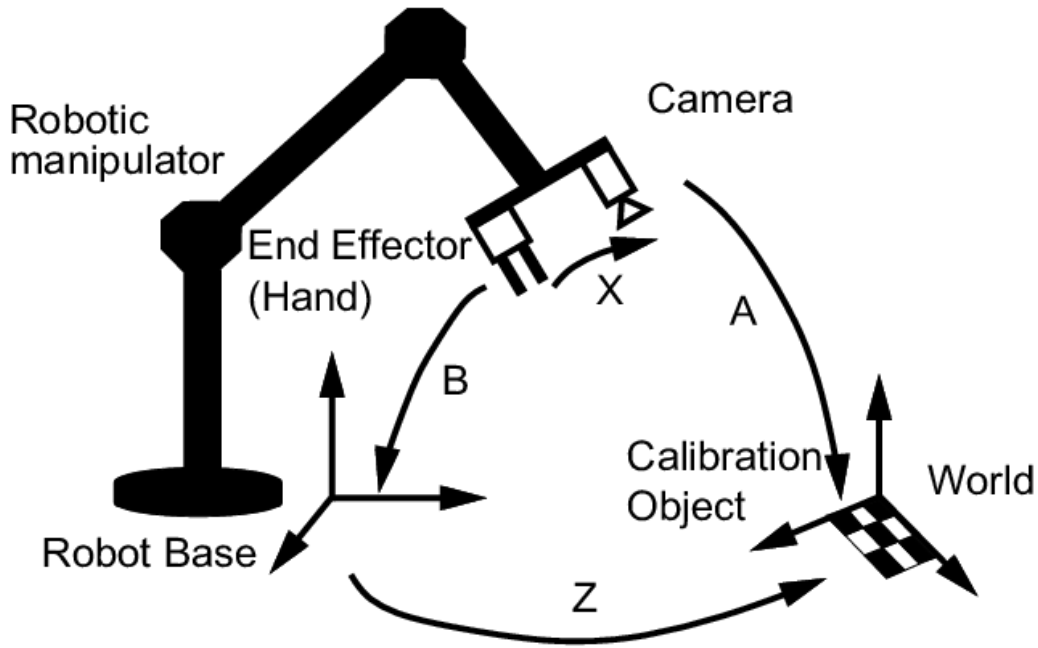
Intrinsic Calibration

Extrinsic Calibration

Key Concepts
Classical Calibration Formulation

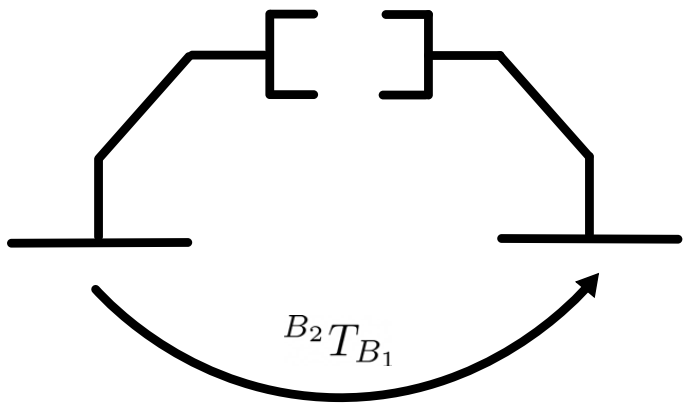
Hand-Eye Formulation

$$AX = ZB$$



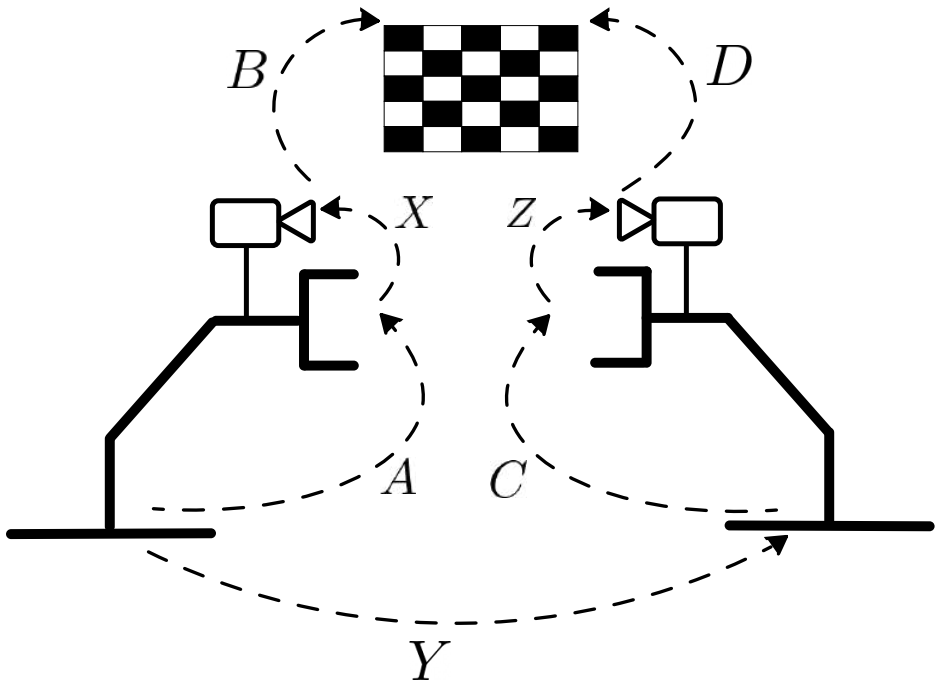
Multi-Robot Calibration
Concept

- Additional calibration of base to base transformation



Multi-Robot Calibration
Hand-eye formulation for multiple robots.

$$AXB = YCZD$$



Methodology

Literature Gathering
Exclusion Criteria

- Irrelevant titles/keywords;
- Not in English;
- Conference Papers;
- Grey Literature;
- Older than 2018.

Literature Gathering
Exclusion Criteria

- Irrelevant titles/keywords;
- Not in English;
- Conference Papers;
- Grey Literature;
- Older than 2018.

Literature Gathering
Exclusion Criteria

- Irrelevant titles/keywords;
- Not in English;
- Conference Papers;
- Grey Literature;
- Older than 2018.

Literature Gathering
Exclusion Criteria

- Irrelevant titles/keywords;
- Not in English;
- Conference Papers;
- Grey Literature;
- Older than 2018.

Literature Gathering
Exclusion Criteria

- Irrelevant titles/keywords;
- Not in English;
- Conference Papers;
- Grey Literature;
- Older than 2018.

Literature Gathering
Inclusion Criteria

- More than 30 citations;
- From reputable journals with High Impact Factor;
- From reputable conferences like IROS.

Literature Gathering
Inclusion Criteria

- More than 30 citations;
- From reputable journals with High Impact Factor;
- From reputable conferences like IROS.

Literature Gathering
Inclusion Criteria

- More than 30 citations;
- From reputable journals with High Impact Factor;
- From reputable conferences like IROS.

Literature Gathering
Culling

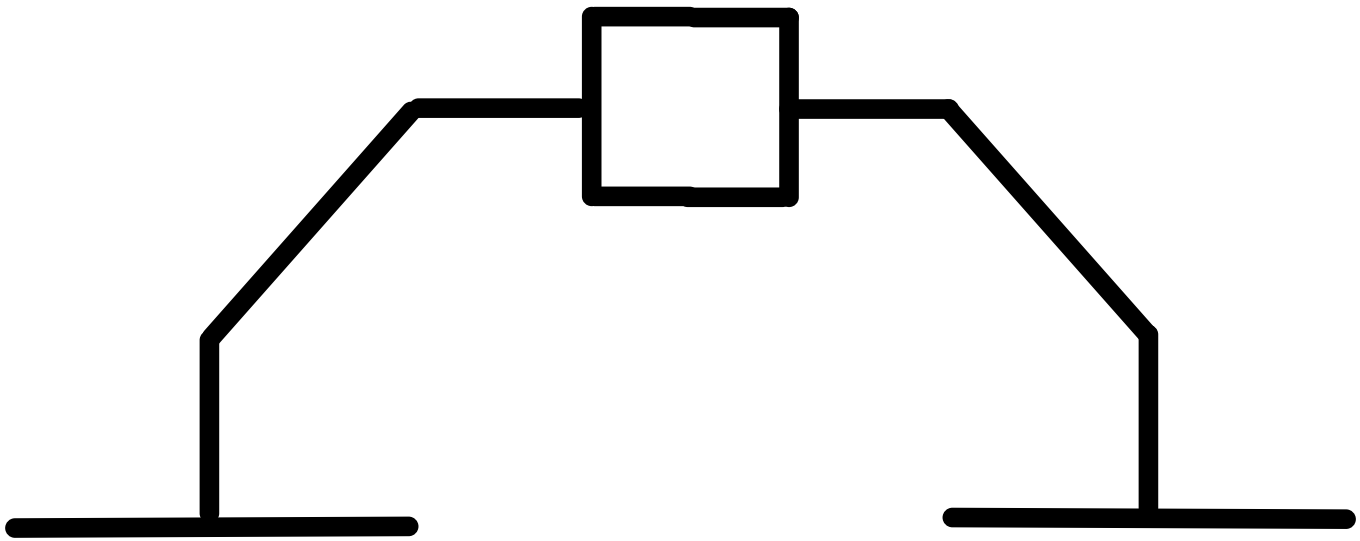
Low number of scientific articles in the field

Filtering based on bibliometric data ineffective

Manual Culling necessary

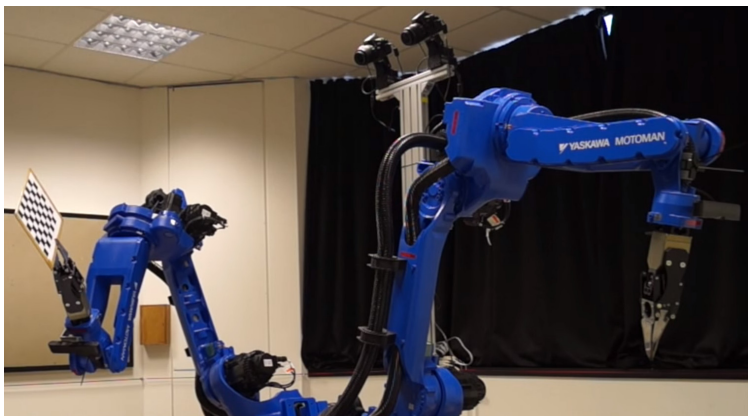
Findings

Experimental Setups
Sensorless Approaches

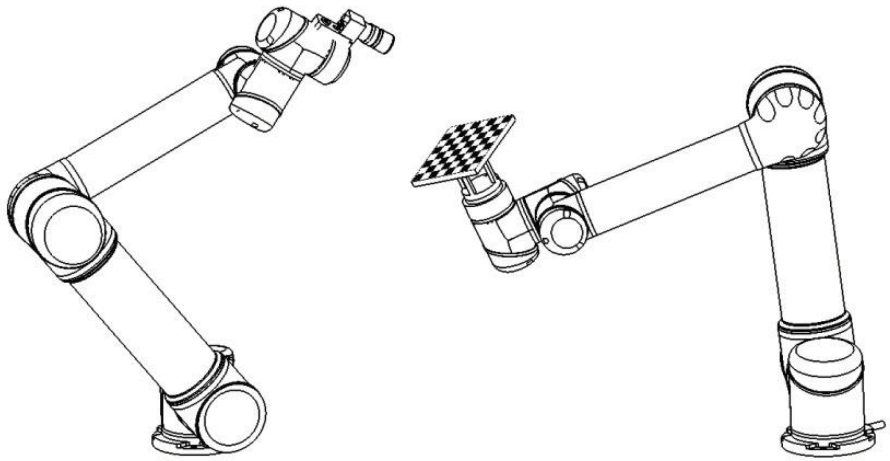


TCP's holding a rigid coupling.

Experimental Setups
Hand-eye



Fu *et al.*[1].



Khan *et al.*[2].

Mathematical Approaches

Closed Form Solutions

Iterative Solutions

Hybrid Solutions

Mathematical Approaches

Closed Form Solutions

Iterative Solutions

Hybrid Solutions

Conclusion

Conclusion

- Multi-Robot calibration is steadily growing, thus being a great area to research.
- Current gaps are :
  - Limitations with multi-modal systems;
  - Most works are not scalable to more than 2 robots.

References

[1] Z. Fu, J. Pan, E. Spyrakos-Papastavridis, X. Chen, and M. Li, "A Dual Quaternion-Based Approach for Coordinate Calibration of Dual Robots in Collaborative Motion,", 2020. DOI: 10.1109/LRA.2020.2988407.

[2] A. Khan, G. Aragon-Camarasa, L. Sun, and J. P. Siebert, "On the calibration of active binocular and RGBD vision systems for dual-arm robots,", 2016. DOI: 10.1109/ROBIO.2016.7866616.

Conclusion

- Multi-Robot calibration is steadily growing, thus being a great area to research.
- Current gaps are :
  - Limitations with multi-modal systems;
  - Most works are not scalable to more than 2 robots.

References

[1] Z. Fu, J. Pan, E. Spyrakos-Papastavridis, X. Chen, and M. Li, "A Dual Quaternion-Based Approach for Coordinate Calibration of Dual Robots in Collaborative Motion,", 2020. DOI: 10.1109/LRA.2020.2988407.

[2] A. Khan, G. Aragon-Camarasa, L. Sun, and J. P. Siebert, "On the calibration of active binocular and RGBD vision systems for dual-arm robots,", 2016. DOI: 10.1109/ROBIO.2016.7866616.

Conclusion

- Multi-Robot calibration is steadily growing, thus being a great area to research.
- Current gaps are :
  - Limitations with multi-modal systems;
  - Most works are not scalable to more than 2 robots.

References

[1] Z. Fu, J. Pan, E. Spyrakos-Papastavridis, X. Chen, and M. Li, "A Dual Quaternion-Based Approach for Coordinate Calibration of Dual Robots in Collaborative Motion,", 2020. DOI: 10.1109/LRA.2020.2988407.

[2] A. Khan, G. Aragon-Camarasa, L. Sun, and J. P. Siebert, "On the calibration of active binocular and RGBD vision systems for dual-arm robots,", 2016. DOI: 10.1109/ROBIO.2016.7866616.

A Comprehensive Review of Extrinsic Calibration Methods for Multi Robot systems

Bruno Silva - *Author*
Miguel Oliveira - *Advisor*
Eurico Pedrosa - *Advisor*

University of Aveiro
PhD. in Mechanical Engineering.

January 6, 2025