Introduction to Robotics

Summary

Shuang Li, Jianwei Zhang
[sli, zhang]@informatik.uni-hamburg.de

University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics
Technical Aspects of Multimodal Systems

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Outline

Outline (cont.)

Conclusion and Outlook

Overall Summary

Introduction

+ Definition;
+ Basic components;
+ DOF;
- Classification

Spatial Description and Transformations

+ Specification of position and orientation;
+ Rotation matrices, their inverse and their operations;
+ Homogeneous transformations;
+ Transformation equations [5, 30, 6, 4];
+ More on presentation of orientation

Forward Kinematics and Robot Description

+ DH-conventions and their applications (classic or modified);
+ Universal Robot Description Format (URDF)

Overall Summary (cont.)

Inverse Kinematics

+ Difference and problems of forward and inverse kinematics;
– Algebraic and geometric solution of inverse kinematics;

Jacobian

+ Differential motion and velocity;
– velocity propagation;
+ Jacobian-matrices;
+ Singularities [5, 30, 6, 4]

Trajectory Generation

+ Tasks and constraints;
+ Trajectory generation methods;
– Polynomial solutions between two and four points;
+ Linear motion in cartesian space and problems;
– Factors of an optimal motion;
+ Concepts and properties of B-Spline interpolation;
– B-Spline basis functions [30, 6, 4, B-Spline Literature]

Overall Summary (cont.)

Dynamics

+ Problems;
+ Newton-Euler equations and Lagrangian Equations;
– Solution for arms with 1 or 2 joints, multiple joints as excercise;
+ Structure of a dynamical equation [30, 6, 4]

Control

– Control systems of a PUMA robot;
– Linear and model-based control;
+ PID controller;
+ Control concepts in Cartesian space [30, 6, 4]

Sensors

○ Classification;
+ Intrinsic sensors, principle and application in control;
– extrinsic sensors [30, 6, 4]

Overall Summary (cont.)

Path planning

- \+ Configuration space;
- – Object representation;
- – Discretized Space Planning;
- \+ Potential field method;
- \+ Probabilistic approaches;
- \+ Rapidly-exploring Random Trees;
- – Task and Manipulation Planning

Control architectures

- – Subsumption;
- – CMAC;
- – Hierarchical

Additional references: [31, 32, 33, 34]

Summary – Control

- Industrial Robots:
  - position control with PID controllers
  - featuring gravity compensation
- Research:
  - model-based control
  - hybrid force-position control
  - `under-actuated control`
  - `backwards controllable` (`direct drive`, `artificial muscle`) structure
  - external-sensor based control
    → Intelligent Robots/Applied Sensor Technology

Summary – Mechanical Structures of Robots

Things we talked about

- Open chain of rotational joints
- Hybrid joints for rotational and translational motion (SCARA, Stanford)
- Mobile robots, running machines

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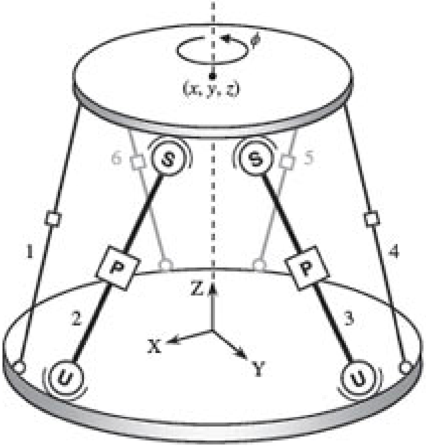
Things we did not talk about

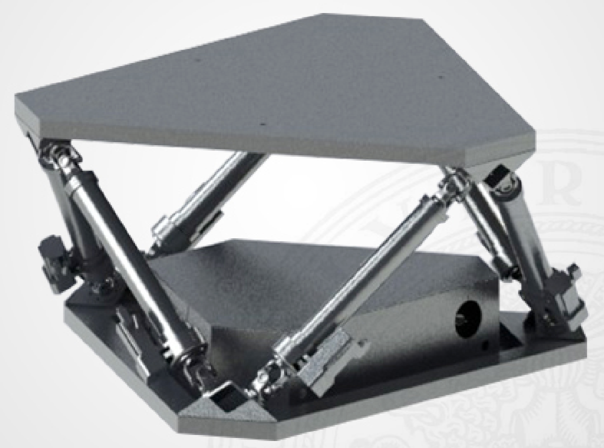
- Closed chain, including Steward Mechanism [30, p. 279]
- Drive without motors

The Stewart-Platform

- Tool plate mounted to base plate with six translational joints (usually hydraulic) called `leg`
- `Legs` are connected to the plates with universal joints
- Mathematically 6-DOF configuration space without singularities
- Parallel mechanism provides high payload
  - Sequential manipulator applies forces and torques unequally

The Stewart-Platform (cont.)





Summary – Algorithms

- Transformations
- Forward and inverse kinematics
- Trajectory generation (e.g. linear Cartesian trajectory)
- Approximated representation of robot joints and objects
- Search algorithms
- Further path planning algorithms
- Sensor fusion
- Vision
  - detection (static, dynamic)
  - reconstruction of position and orientation
- Action planning
- Sensor guided motion

Outline

Outline (cont.)

Conclusion and Outlook

Underlying robot-technique as described, additionally:

External Recognition

- Reliable measurements of the environment;
- Scene interpretation

Knowledge base

- About environment;
- Its own state;
- Everyday knowledge comparable to a human

Autonomous planning

- Action;
- Coarse motion;
- Grasping;
- Sensor data acquisition

Intelligent Robots (cont.)

Human friendly interface

- Understanding of naturally spoken commands;
- Generation of robot actions;
- Solving of disambiguity in context-aware situations

Adaptive Control

- Evolution instead of programming;
- Ability to learn

Autonomous Planning Systems

Action Planning

- Task-Specification;
- State representation;
- Task-decomposition;
- Action-sequence generation

Motion Planning

- Representation of the robot and the environment;
- Calculation and representation of configuration space;
- Search algorithms

Planning of Sensing

- Which sensors;
- Which time intervals;
- Where to measure;
- Internal and external parameters of the sensor

Sensor driven motion

Goal

Intelligent Control including the ability to adapt to different situations and to react to uncertainties

Control Architecture

Integration of perception, planning and actions

Tasks of sensor data processing

Position detection;
Proximity detection;
Slip detection;
Success confirmation;
Error detection;
Inspection

Sensor driven motion (cont.)

Applied sensors

- Tactile sensors;
- Vision systems;
- Force-torque measurement systems;
- Distance sensors

Strategies

- `calibrated` based on absolute reference values;
- `uncalibrated` based on relative information

Types of perception

- `passive` based on a certain sensor-actor configuration;
- `active` depending on the plan for sensing

Future Commercial Robots

will be:

- dexterous
- smaller
- faster
- lightweight
- powerful
- intelligent
- easier to operate
- cheaper

Challenges in the Field of Robotics

Methods

Symbolical understanding of the environment;
Integrated sensor-motor-coupling;
Self-learning

Systems

Synergetic multi-sensor;
Agile mobility;
Dexterous manipulation capabilities

Technical

Sensor complexity similar to a human;
New drive types;
Nano-robots;
Multifinger hand;
Anthropomorphic robots;
Flying robots

Continuing Education at University of Hamburg

Intelligent Robots Project
: Build a complex robotic system from the available hardware at TAMS. Current Hardware includes PR2, TASER, 2 KUKA lightweight arms, 2 Mitsubishi PA10-6C, UR5 Arm, 4 Turtlebots, Shadow Hand C6, Shadow Hand C5, Robotiq adaptive gripper, SCHUNK gripper, 2 Barret Hands...

Intelligent Robots/Applied Sensor Technology Lecture
: Intrinsic and Extrinsic sensor technology and their application for intelligent robotic systems.

Machine Learning Lecture
: Machine learning techniques allow robots to learn from observation and experience

Neural Networks Lecture
: Neural Networks allow robots to learn and offer new approaches to planning and control

Image Processing I&II Lecture
: Image processing is required for robots to observe the environment and recognize/classify/detect objects and humans

Continuing Education at University of Hamburg (cont.)

Knowledge Processing Lecture
: The gained knowledge from observance and sensing has to be processed efficiently

Language Processing Lecture
: How to extract knowledge and information from human speech

Real-Time Systems Lecture at TUHH
: Robots have to process information and act in Real-Time environments

Fundamentals of Control Technology Lecture at TUHH
: Control Technology is required for the technical control of robotic systems.
Advanced Lecture with large prerequisites.

Bibliography

[1] G.-Z. Yang, R. J. Full, N. Jacobstein, P. Fischer, J. Bellingham, H. Choset, H. Christensen, P. Dario, B. J. Nelson, and R. Taylor, "Ten robotics technologies of the year," 2019.

[2] J. K. Yim, E. K. Wang, and R. S. Fearing, "Drift-free roll and pitch estimation for high-acceleration hopping," in *2019 International Conference on Robotics and Automation (ICRA)*, pp. 8986–8992, IEEE, 2019.

[3] J. F. Engelberger, *Robotics in service*.
MIT Press, 1989.

[4] K. Fu, R. González, and C. Lee, *Robotics: Control, Sensing, Vision, and Intelligence*.
McGraw-Hill series in CAD/CAM robotics and computer vision, McGraw-Hill, 1987.

[5] R. Paul, *Robot Manipulators: Mathematics, Programming, and Control: the Computer Control of Robot Manipulators*.
Artificial Intelligence Series, MIT Press, 1981.

[6] J. Craig, *Introduction to Robotics: Pearson New International Edition: Mechanics and Control*.
Always learning, Pearson Education, Limited, 2013.

Bibliography (cont.)

[7] T. Flash and N. Hogan, "The coordination of arm movements: an experimentally confirmed mathematical model," *Journal of neuroscience*, vol. 5, no. 7, pp. 1688–1703, 1985.

[8] T. Kröger and F. M. Wahl, "Online trajectory generation: Basic concepts for instantaneous reactions to unforeseen events," *IEEE Transactions on Robotics*, vol. 26, no. 1, pp. 94–111, 2009.

[9] W. Böhm, G. Farin, and J. Kahmann, "A Survey of Curve and Surface Methods in CAGD," *Comput. Aided Geom. Des.*, vol. 1, pp. 1–60, July 1984.

[10] J. Zhang and A. Knoll, "Constructing Fuzzy Controllers with B-spline Models - Principles and Applications," *International Journal of Intelligent Systems*, vol. 13, no. 2-3, pp. 257–285, 1998.

[11] M. Eck and H. Hoppe, "Automatic Reconstruction of B-spline Surfaces of Arbitrary Topological Type," in *Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '96, (New York, NY, USA), pp. 325–334, ACM, 1996.

Bibliography (cont.)

[12] M. C. Ferch, *Lernen von Montagestrategien in einer verteilten Multiroboterumgebung*. PhD thesis, Bielefeld University, 2001.

[13] J. H. Reif, "Complexity of the Mover's Problem and Generalizations - Extended Abstract," *Proceedings of the 20th Annual IEEE Conference on Foundations of Computer Science*, pp. 421–427, 1979.

[14] J. T. Schwartz and M. Sharir, "A Survey of Motion Planning and Related Geometric Algorithms," *Artificial Intelligence*, vol. 37, no. 1, pp. 157–169, 1988.

[15] J. Canny, *The Complexity of Robot Motion Planning*. MIT press, 1988.

[16] B. Siciliano and O. Khatib, *Springer handbook of robotics*. Springer, 2016.

[17] P. Sermanet, C. Lynch, Y. Chebotar, J. Hsu, E. Jang, S. Schaal, S. Levine, and G. Brain, "Time-contrastive networks: Self-supervised learning from video," in *2018 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 1134–1141, IEEE, 2018.

Bibliography (cont.)

[18] C. Finn, P. Abbeel, and S. Levine, "Model-agnostic meta-learning for fast adaptation of deep networks," *arXiv preprint arXiv:1703.03400*, 2017.

[19] R. Brooks, "A robust layered control system for a mobile robot," *Robotics and Automation, IEEE Journal of*, vol. 2, pp. 14–23, Mar 1986.

[20] M. J. Mataric, "Interaction and intelligent behavior.," tech. rep., DTIC Document, 1994.

[21] M. P. Georgeff and A. L. Lansky, "Reactive reasoning and planning.," in *AAAI*, vol. 87, pp. 677–682, 1987.

[22] J. Zhang and A. Knoll, *Integrating Deliberative and Reactive Strategies via Fuzzy Modular Control*, pp. 367–385.
Heidelberg: Physica-Verlag HD, 2001.

[23] J. S. Albus, "The nist real-time control system (rcs): an approach to intelligent systems research," *Journal of Experimental & Theoretical Artificial Intelligence*, vol. 9, no. 2-3, pp. 157–174, 1997.

[24] A. Meystel, "Nested hierarchical control," 1993.

[25] G. Saridis, "Machine-intelligent robots: A hierarchical control approach," in *Machine Intelligence and Knowledge Engineering for Robotic Applications* (A. Wong and A. Pugh, eds.), vol. 33 of *NATO ASI Series*, pp. 221–234, Springer Berlin Heidelberg, 1987.

[26] T. Fukuda and T. Shibata, "Hierarchical intelligent control for robotic motion by using fuzzy, artificial intelligence, and neural network," in *Neural Networks, 1992. IJCNN., International Joint Conference on*, vol. 1, pp. 269–274 vol.1, Jun 1992.

[27] R. C. Arkin and T. Balch, "Aura: principles and practice in review," *Journal of Experimental & Theoretical Artificial Intelligence*, vol. 9, no. 2-3, pp. 175–189, 1997.

[28] E. Gat, "Integrating reaction and planning in a heterogeneous asynchronous architecture for mobile robot navigation," *ACM SIGART Bulletin*, vol. 2, no. 4, pp. 70–74, 1991.

[29] L. Einig, *Hierarchical Plan Generation and Selection for Shortest Plans based on Experienced Execution Duration.*
Master thesis, Universität Hamburg, 2015.

[30] J. Craig, *Introduction to Robotics: Mechanics & Control. Solutions Manual.*
Addison-Wesley Pub. Co., 1986.

Bibliography (cont.)

[31] H. Siegert and S. Bocionek, *Robotik: Programmierung intelligenter Roboter: Programmierung intelligenter Roboter*.
Springer-Lehrbuch, Springer Berlin Heidelberg, 2013.

[32] R. Schilling, *Fundamentals of robotics: analysis and control*.
Prentice Hall, 1990.

[33] T. Yoshikawa, *Foundations of Robotics: Analysis and Control*.
Cambridge, MA, USA: MIT Press, 1990.

[34] M. Spong, *Robot Dynamics And Control*.
Wiley India Pvt. Limited, 2008.