Project in Advanced Robotics

Christoffer Sloth
chsl@mmmi.sdu.dk

SDU Robotics
The Maersk Mc-Kinney Moller Institute
University of Southern Denmark

Agenda

Introduction

Project Proposals

Knowledge: [1]
Having completed this course, the student has:

- Expert-level knowledge within the methodological background of subject areas included in the project

Skills:
Having completed this course, the student has:

- Theoretical skills within the chosen subject area
- Programming and project management skills

Competencies:
Having completed this course, the student has:

- Ability to solve a complex problem independently and/or in groups
- Ability to work systematically and implement complex solutions
- Ability to report the theoretical subject and project outcome at an expert level

[1] https://odin.sdu.dk/sitecore/index.php?a=fagbesk&id=61253&listid=7215&lang=en

The project should either focus on some advanced topic within computer vision and/or robot control, and should demonstrate that you are capable of applying the chosen method to a practical problem.

Requirements

- The project should be documented in a report of maximum 50 pages.
- The report should clearly state who has contributed to each section.
- An oral exam is conducted based on the report (pass/fail)).
- The project should be demonstrated on May 12. Details follow later.
- The report should be handed in on May 26 at 12:00.

You should form groups of 3-4 persons and make a prioritized list of three projects (see list of projects in the following slides).

Procedure for assignment of project

- Each group must submit a list of projects via the assignment on itslearning no later than February 10 at 12:00.
- Projects and supervisors are announced on February 14.

Project Proposals

Introduction

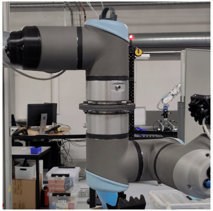
Project Proposals

Benchmarking of Kinesthetic Robot Guidance
Focus: Robot Control

Kinesthetic teaching is the process of grabbing the robot and moving it to teach it a skill. A study[2] from 2014 indicates that kinesthetic cannot transfer skills properly. This might be due to choice of control. For this reason it is necessary to evaluate and compare the combination of different controllers and robots. The study[3] addresses this issue.

The project can cover the following topics:

- Implementation and evaluation of robot controllers, such as the admittance controller.
- Planning and execution of robot experiments in simulation and in the laboratory.
- Comparison of controller gains, language (`URscript` / `Python`), etc..



[2] A. Muxfeldt, J.-H. Kluth, and D. Kubus, "Kinesthetic teaching in assembly operations – a user study,", Springer International Publishing, 2014. DOI: 10.1007/978-3-319-11900-7_45.

[3] R. J. Kirschner, F. Martineau, N. Mansfeld, *et al.*, "Manual maneuverability: Metrics for analysing and benchmarking kinesthetic robot guidance,", IEEE, 2022. DOI: 10.1109/iros47612.2022.9981864.

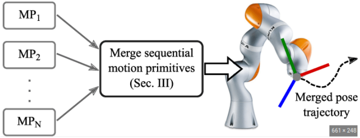
Optimization to Blend Several Robot Skills

Focus: Learning from Demonstration (LfD) via optimization

Learning from Demonstration (e.g. Dynamic Movement Primitives (DMP)) has been getting attention in the robotics field to reproduce human skills and transfer them into a robot. However, it is not easy to improve or generalize the learned behaviours unless we demonstrate human skills again. Therefore, this challenge can be resolved by reusing and blending previous data[4][5] to create new behaviours.

The project will cover the following topics:

- Choose and implement suitable LfD methods to a task (possibly two).
- Implementation optimization methods to blend the skills. (e.g. Quadratic Programming)
- Evaluating the learned paths from each method.



[4] N. Jaquier, Y. Zhou, J. Starke, *et al.*, "Learning to sequence and blend robot skills via differentiable optimization," *IEEE Robotics and Automation Letters*, vol. 7, no. 3, pp. 8431–8438, 2022.

[5] M. Saveriano, F. Franzel, and D. Lee, "Merging position and orientation motion primitives," in *2019 International Conference on Robotics and Automation (ICRA)*, 2019, pp. 7041–7047.

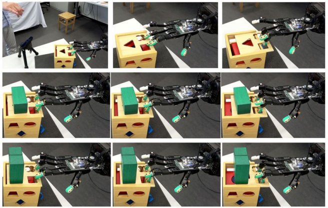
Adaptive Motion to Variant Compliance

Focus: Compliance Adaptation via Robot Control

Human can adapt their behaviours to various task situations by changing the compliance of their motion. Therefore, it is efficient to transfer human motions to a robot directly, and this approach normally works fine. However, when given a new task situation with different force fields, there could be the discrepancy between the learned motion and the required motion to achieve the new task, which sometimes leads to task failure. To this end, we can take a parametric model estimation approach to deal with new task situations.[6]

The project will cover the following topics:

- Implementation parametric adaptation methods to generate compliance profile. (e.g. Gradient method)
- Collecting and learning human demonstration motion. (e.g. DMP or Gaussian Mixture Model (GMM))
- Defining different task situations and evaluating success rates.



[6] C. Zeng, S. Li, B. Fang, *et al.*, "Generalization of robot force-relevant skills through adapting compliant profiles," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 1055–1062, 2022.

Kernelized Movement Primitives for Manipulation Skills

Focus: Learning from Demonstration, Robot Control

Kernelized Movement Primitives[7] is a probabilistic approach to learning from demonstration that can encode dependencies between high-dimensional inputs to adapt the behavior to varying conditions. This way uncertainty in the demonstration can be used to adapt the compliance of the robot controller[8], or the geometry of manipulation skills can be used to vary compliance parameters[9].

The project will cover the following topics:

- Learning compliant skills from multiple demonstrations.
- Encoding the behavior as a KMP.
- Conditioning a KMP to vary compliance parameters.

[7] Y. Huang, L. Rozo, J. Silvério, *et al.*, "Kernelized movement primitives," *The International Journal of Robotics Research*, vol. 38, no. 7, pp. 833–852, 2019.

[8] J. Silvério, Y. Huang, F. J. Abu-Dakka, *et al.*, "Uncertainty-aware imitation learning using kernelized movement primitives," in *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, 2019, pp. 90–97.

[9] F. J. Abu-Dakka, Y. Huang, J. Silvério, *et al.*, "A probabilistic framework for learning geometry-based robot

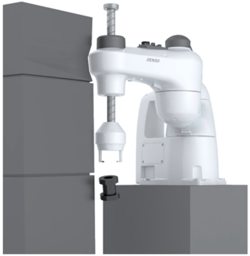
Adapting Learned Trajectories in Response to Collisions

Focus: Robot Control, Learning from Demonstration

Often, changes in the robot's workspace will cause a skill that was learned from demonstration to fail due to collisions with the environment. It would be beneficial if the robot could react to a collision, explore the environment, and learn how to adapt the skill to the change in the environment.

The project will cover the following topics:

- Collision detection using observers, e.g., the Generalized Momentum Observer[10].
- Tactile exploration of the environment.
- Local adaptation of a DMP by exploiting compactly supported basis functions[11].



[10] A. Wahrburg, E. Morara, G. Cesari, *et al.*, "Cartesian contact force estimation for robotic manipulators using kalman filters and the generalized momentum," in *2015 IEEE International Conference on Automation Science and Engineering (CASE)*, IEEE, 2015, pp. 1230–1235.

[11] M. Ginesi, N. Sansonetto, and P. Fiorini, "Overcoming some drawbacks of dynamic movement primitives," *Robotics and Autonomous Systems*, vol. 144, p. 103 844, 2021.

Pose distribution estimation for insertion

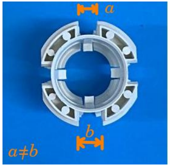
Focus: Computer Vision

Many parts in industrial assembly have almost discrete rotational symmetry. Traditional pose estimation estimates a single pose, so if the system cannot distinguish between the almost symmetric poses, the insertion action must be manually adjusted to try insertion for each pose in the set. The manual involvement can potentially be avoided if a probability distribution over object poses is estimated instead of a single pose.

In this project you will train a modified version of Implicit-PDF[12] to estimate a distribution over the in-plane position and orientation of a part. The training should be done using synthetic images, e.g. using BlenderProc.

Topics:

- Deep Learning
- Pose distribution estimation



[12] K. Murphy, C. Esteves, V. Jampani, *et al.*, "Implicit-pdf: Non-parametric representation of probability distributions on the rotation manifold," *arXiv preprint arXiv:2106.05965*, 2021.

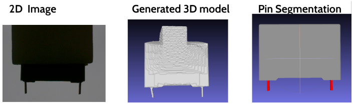
Visual hull and pin segmentation

Focus: Computer Vision

Insertion of electrical components is difficult as the small *pins* have low tolerance. Additionally, CAD models are often imprecise further complicating the procedure.
In this project the 3D model is generated online and a deep learning network is trained to segment the pins. The insertion can then be performed without a CAD model.
In this project you will implement a method to generate 3D data from 2D images (e.g. visual hull). You will train a neural network for segmentation of 3D data.
The system can first be created in simulation and then tested on real objects. Additionally, you can create training data from the real world and mix with the synthetic data.

Topics:

- Camera Matrix
- 3D from 2D
- Deep Learning on point clouds
- Domain Adaptation



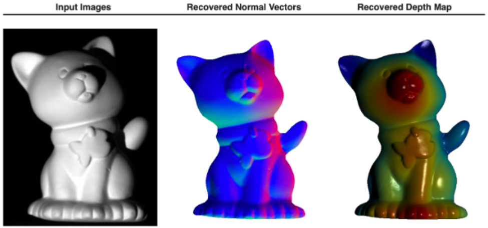
Photometric stereo depth reconstruction

Focus: Computer Vision

This project aims to reconstruction surface topology using the photometric stereo (PS) technique. PS is a classical technique which estimates surface normals using multiple pixel observations with varying lighting positions. In order to find a tractable solution some assumptions are needed such as known light positions, parallel rays, Lambertian BRDF, known camera calibration, etc. Modern approaches aim to lift some of these assumptions. The project can use publicly available data, or new data can be collected.

Outcomes:

- Literature review and analysis of method boundaries.
- An implementation of photometric stereo calibration and reconstruction.
- Visualizations and quantification of accuracy.



Visual SLAM for autonomous driving
Focus: Computer Vision

The project's goal is to develop a SLAM system which can successfully reconstruct trajectory on the KITTI visual odometry data set. A solution may be inspired and also based on published entries to the KITTI odometry benchmark. The report needs to very clearly indicate which parts are own innovations.

Outcomes:

- Development of a comprehensive SLAM method
- Use of grayscale or color image information
- Evaluation of algorithm performance using KITTI GT
- Optional: use of LIDAR and/or stereo information

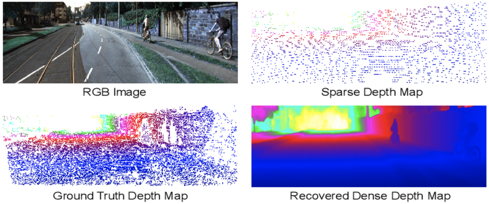
Deep Learning Based Depth Estimation

Focus: Computer Vision

Depth reconstruction using neural networks is a promising approach which can be more robust than active sensing, while requiring only 2D image input. The project's aim is to reconstruct depth maps or point clouds of a 3d scene given multiple RGB images from calibrated cameras. The approach would most likely be based on a sparse classical multiview-reconstruction followed by a multi-view depth completion network. Training data should be generated using Blenderproc. A multi-view scene for real data collection is available as part of the FacilityCobot project.

Outcomes:

- Literature review.
- Development of a multi-view depth reconstruction pipeline.
- Simple synthetic data generation using blenderproc.



End-to-end 3D detection

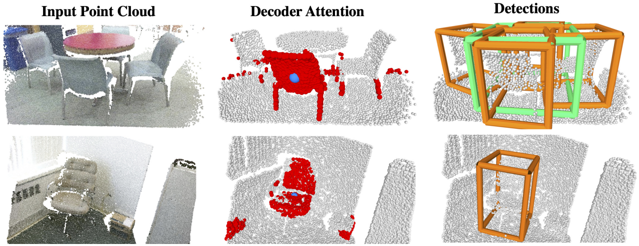
Focus: Computer Vision

Learnt 3D detection could mitigate some of the problems occurring from using 2D detectors in pose estimation pipelines.

In this project you will understand 3DETR[13] and adapt the end-to-end 3D detector to an industrial setting, detecting known objects with center point predictions from a depth image. Optionally, you will extend the method with color information and/or multiple views.

Topics:

- Deep Learning
- Point Clouds
- Transformers



[13] I. Misra, R. Girdhar, and A. Joulin, "An End-to-End Transformer Model for 3D Object Detection," in *ICCV*, 2021.

Your Own Project

Focus: Computer Vision and/or Robot Control

A project which you define.

To be considered, you need to write a convincing, motivated application (up to 1 page), which describes what you want to address, and how to achieve it.