Czech
Technical
University
in Prague

F3

Faculty of Electrical Engineering
Department of Cybernetics

Bachelor Project

Disassembly Path Planning

Petr Ježek

Supervisor: Ing. Vojtěch Vonásek, Ph.D.
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BACHELORʹS THESIS ASSIGNMENT

I. Personal and study details

Student's name:	**Jeġek Petr**	Personal ID number:	**483566**
Faculty / Institute:	**Faculty of Electrical Engineering**		
Department / Institute:	**Department of Cybernetics**		
Study program:	**Cybernetics and Robotics**		

II. Bachelorʹs thesis details

Bachelorʹs thesis title in English:

Disassembly Path Planning

Bachelorʹs thesis title in Czech:

Pl§nov§n² cest v ¼loze rozkl§d§n² objektŢ

Guidelines:

1. Get familiar with the assembly and disassembly path planning [1] and sampling-based planning [2].
2. Implement the matrix-based disassembly planning Breakout local search [6]. Consider 2D solid objects (represented by triangle mesh) without rotations.
3. Extend [6] by consider rotations of the objects.
4. Implement a sampling-based planner for disassembly planning,e.g., [5]. Consider 2D solid objects with rotations.
5. Extend method from 4) by precomputing manipulation paths for the active objects using a fast sampling-based planner, e.g. [3,4].
6. Experimentally verify performance of methods from 3), 4) and 5) in a suitable benchmark inspired by [5].

Bibliography / sources:

[1] Ghandi, Somay®, and Ellips Masehian. "Review and taxonomies of assembly and disassembly path planning problems and approaches." Computer-Aided Design 67 (2015): 58-86.
[2] LaValle, Steven M. Planning algorithms. Cambridge university press, 2006.
[3] J. Denny, R. Sandstr°m, A. Bregger, and N. M. Amato. Dynamic region-biased rapidly-exploring random trees. In Twelfth International Workshop on the Algorithmic Founda-tions of Robotics (WAFR), 2016.
[4] Von§sek, V., PĐni¦ka, R. & Kozl²kov§, B. Searching Multiple Approximate Solutions in Configuration Space to Guide Sampling-Based Motion Planning. J Intell Robot Syst 100, 1527ï1543 (2020). https://doi.org/10.1007/s10846-020-01247-4
[5] Duc Thanh Le, Juan Cort®s, and Thierry Sim®on. A path planning approach to (dis)assembly sequencing. In 2009 IEEE International Conference on Automation Science and Engineering, pages 286ï291. IEEE, 2009.
[6] Somay® Ghandi and Ellips Masehian. A breakout local search (BLS) method for solving the assembly sequence planning problem. Engineering Applications of Artificial Intelligence, 39:245ï266, 2015.

Name and workplace of bachelorʹs thesis supervisor:

Ing. VojtĐch Von§sek, Ph.D., Multi-robot Systems, FEE

Name and workplace of second bachelorʹs thesis supervisor or consultant:

Date of bachelorʹs thesis assignment: **08.01.2021** Deadline for bachelor thesis submission: **21.05.2021**

Assignment valid until: **30.09.2022**

Ing. VojtĐch Von§sek, Ph.D. Supervisorʹs signature	prof. Ing. Tom§ģ Svoboda, Ph.D. Head of departmentʹs signature	prof. Mgr. Petr P§ta, Ph.D. Deanʹs signature

III. Assignment receipt

The student acknowledges that the bachelor’s thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor’s thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt

Student’s signature

Acknowledgements

I wish to thank Ing. Vojtěch Vonásek, Ph.D. for supervising this thesis, valuable guidance and continuous encouragement. Moreover, my thanks go to my family and girlfriend for neverending support.

Declaration

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university theses.

Prague, date 18.5.2021

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Petr Ježek

Abstract

Disassembly path planning is an important sector of robot manipulation and manufacturing of End-of-life product. This thesis focuses on developing suitable tools for 2D disassembly planning using a matrix heuristic method, sampling-based planners, such as Rapidly-exploring Random Tree algorithm and guided path search along the precomputed disassembly paths represented by the Reeb graph. Moreover, the goal is to provide a state-of-the-art of disassembly planning and disassembly path planning problems and design suitable benchmarks to properly evaluate the proposed disassembly planners.

Keywords: Disassembly, 2D assembly, Path planning, Rapidly-exploring Random Trees, Guided search, Matrix heuristic

Abstrakt

Plánování cest v úloze rozkládání objektů je důležitým prvkem při plánování pohybu a manipulaci robotů a zpracovávání a recyklaci End-of-life produktů. Tato práce se zaměřuje na návrh vhodných plánovacích algoritmů pro 2D prostředí za použití heuristických metod, algoritmů založených na vzorkování, jako například algoritmus Rychle rostoucích náhodných stromů a také na hledání cest podél předpočítaných trajektorií, reprezentované Reeb grafem. Dalším cílem je detailně popsat problém rozkládání objektů a navrhnout vhodné hlavolamy, na kterých bude možné otestovat implementované algoritmy.

Klíčová slova: Rozkládání objektů, 2D Hlavolamy, Plánování cest, Rychle rostoucí náhodné stromy, Řízené prohledávání, Maticová heuristika

Contents

Chapter 1

Introduction

The problem of disassembly planning is well known and highly important in industrial product manufacturing of End-of-life products [1, 2, 3], robot manipulation in robot simulation software, such as *Process Simulate*, and structural bioinformatics [4, 5]. The general concept is to take a given object apart, so to extract all parts from an assembly to a disassembled object a disassembly. An assembly with a corresponding disassembly can be seen in Fig. 1.1. Nevertheless, in this thesis, only 2D assemblies are used, such as one in Fig. 1.2.

The problem can be divided into different sub-problems. The main two discussed in this thesis are Disassembly Sequence Planning and Disassembly Path Planning. The first selects a part most likely to be disassembled, and the second plans a disassembly path for the proposed part.

Figure 1.1: Example of complex 3D assembly (right) and disassembly (left), borrowed from [2]

Disassembly planning is applicable for a wide variety of assemblies differing in the number of parts, mobility of components or individual geometry. It follows that disassembly planning is a very complex problem. Generally, it is an NP-Hard problem [6], so for a fast performance, an effective method, often using reliable heuristic, is required. The solution methods are classified according to the completeness, representation of workspace, and way of searching the configuration space.

Many disassembly methods originally come from the motion planning problem, and usually, after some adjustments and improvements, the core idea is applicable to the problem of disassembly planning. The most suitable fast planners appropriate for various assemblies, even though not using any heuristic, are the sampling-based planners. The Rapidly-exploring Random Tree algorithm (RRT) [7] is considered as the breakthrough method whose core idea is used in plenty of contemporary path planners, such as Dynamic Region-biased Rapidly-exploring Random Tree algorithm (DRRRT) [8] or Manhattan-like Rapidly-exploring Random