Robotics and Autonomous Systems 71 (2015) 99–117

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

Support relation analysis and decision making for safe robotic manipulation tasks

Rasoul Mojtahedzadeh *, Abdelbaki Bouguerra, Erik Schaffernicht, Achim J. Lilienthal

Centre for Applied Autonomous Sensor Systems, Örebro University, Fakultetsgatan 1, 70281 Örebro, Sweden

HIGHLIGHTS

- Basic research question is how to decide on the safest object to unload from a container.
- Two approaches to extract support relations between convex objects are proposed.
- Approach based on physics principles if full geometric scene information is available.
- Machine learning based probabilistic approach if information about objects is incomplete.
- Extensive performance analysis using simulated and real-world data.

ARTICLE INFO

Article history:
Available online 31 December 2014

Keywords:
Scene analysis
Machine learning
Decision making
World models
Robotic manipulation

ABSTRACT

In this article, we describe an approach to address the issue of automatically building and using high-level symbolic representations that capture physical interactions between objects in static configurations. Our work targets robotic manipulation systems where objects need to be safely removed from piles that come in random configurations. We assume that a 3D visual perception module exists so that objects in the piles can be completely or partially detected. Depending on the outcome of the perception, we divide the issue into two sub-issues: (1) all objects in the configuration are detected; (2) only a subset of objects are correctly detected. For the first case, we use notions from geometry and static equilibrium in classical mechanics to automatically analyze and extract act and support relations between pairs of objects. For the second case, we use machine learning techniques to estimate the probability of objects supporting each other. Having the support relations extracted, a decision making process is used to identify which object to remove from the configuration so that an expected minimum cost is optimized. The proposed methods have been extensively tested and validated on data sets generated in simulation and from real world configurations for the scenario of unloading goods from shipping containers.

1. Introduction

In robotic manipulation, the task of autonomously selecting an object from a pile that can be safely unloaded is essential. In the context of this paper, safety is reflected through selecting an object from a pile such that removing it leads to as little motion as possible of the other objects in the pile. In other words, we want to avoid causing the other objects to move (e.g., fall down) by removing an object from a pile.

In order to identify which object is the safest to remove first, a robotic manipulation system requires the ability of anticipating the outcomes of its own actions. In industrial automation, the complexity of predicting the effects of selecting objects for manipulation is addressed with known, and well engineered environments [1,2]. However, a reliable prediction of the outcome of removing an object from chaotically stacked piles is more challenging due to issues that real-world environments pose for autonomous systems. Chief among these issues is uncertainty that can be induced by both hardware (e.g., due to noise and limited perception) and software (e.g., due to unreliable object detection and classification).

A challenging real-world environment for autonomous robotic manipulation systems is the contents of shipping containers. In such environments, the objects inside the containers come usually in random configurations due to the shipping process. Fig. 1 shows

* Correspondence to: AASS Research Centre, School of Science and Technology, Örebro University, Fakultetsgatan 1, 70281 Örebro, Sweden.

E-mail addresses: rasoul.mojtahedzadeh@oru.se (R. Mojtahedzadeh), abdelbaki.bouguerra@oru.se (A. Bouguerra), erik.schaffernicht@oru.se (E. Schaffernicht), achim.lilienthal@oru.se (A.J. Lilienthal).

http://dx.doi.org/10.1016/j.robot.2014.12.014
0921-8890/

Fig. 1. A few example snapshots of configurations of objects inside shipping containers at unloading sites.

a few such difficult configurations. To autonomously empty a container, a manipulation system needs two main abilities. First, it needs to be able to create models to reflect how objects in the configuration are physically interacting with each other, i.e., to identify which objects are supporting other objects. Second, it should be able to use the created models to make an optimal decision regarding which object is the safest to remove.

This work is part of a larger research effort aiming at automating the process of unloading shipping containers utilizing with more advanced cognitive abilities [3]. In this paper we focus on automatic scene analysis in order to create high-level symbolic models to describe the physical relations between objects composing a static configuration. We also focus on a decision making process that uses the models to reason about a safe sequence of unloading objects. We assume that only geometrical attributes (shape and pose) of the objects in addition to the point cloud of the target environment are available to our algorithms. Such data, for example, can be obtained by utilizing object detection and pose estimation methods [4–7].

In our previous work reported in [8,9], we considered solid cuboid shape objects and described our initial results of how to build relational scene representation and decision making for safe robotic manipulation tasks for the cases of both complete and incomplete sets of detected objects. In [8], it is assumed that the shape and the pose of all objects in the environment are available, i.e., there is no uncertainty in the data. Such assumption is relaxed in our second work described in [9], where only the shape and the pose of a subset of objects composing the environment are assumed to be available. In the latter work, we used Support Vector Machines (SVMs) to learn the possible support relations by extracting features from pairs of objects and the point cloud of the scene. A probabilistic representation of the support relations is then created to express all possible worlds where an object supports another one. The possible world representation is then used by a decision making process based on minimization of cost of taking unloading actions in the possible worlds.

This article extends the two previous works with the following contributions:

- We consider any solid object with a convex polyhedron shape. Previously, we considered only solid carton boxes, which are one of the most popular goods inside shipping containers [10].
- We describe a faster approach to extracting support relations between pairs of objects in contact with each other using the principle of static equilibrium in classical mechanics.
- In addition to Support Vector Machines (SVMs), which we employed and examined its performance in our previous work [9], we look at Artificial Neural Networks (ANNs) and Random Forests to approximate the probability distribution of support relations between pairs of objects in this work.
- We provide extensive experimental results that show the performance of the proposed approach for each machine learning technique for the three different types of objects (box, cylinder, and barrel).

The rest of this article is organized as follows. Section 2 reviews related research work. In Section 3, terminology and assumptions that we constantly use throughout this article are presented. Section 4 describes our approach to extract support relations between pairs of objects. We describe our decision making process in Section 5. We present the results in Section 6 and conclude the article in Section 7.