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Addressing perception uncertainty induced failure modes in robotic bin-picking

Krishnanand N. Kaipa [a], Akshaya S. Kankanhalli-Nagendra [a], Nithyananda B. Kumbla [a], Shaurya Shriyam [a], Srudeep Somnaath Thevendria-Karthic [a], Jeremy A. Marvel [b], Satyandra K. Gupta [c,*]

[a] Maryland Robotics Center, University of Maryland, MD, USA
[b] National Institute of Standards and Technology, Gaithersburg, MD, USA
[c] Center for Advanced Manufacturing, University of Southern California, CA, USA

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A B S T R A C T

We present a comprehensive approach to handle perception uncertainty to reduce failure rates in robotic bin-picking. Our focus is on mixed-bins. We identify the main failure modes at various stages of the bin-picking task and present methods to recover from them. If uncertainty in part detection leads to perception failure, then human intervention is invoked. Our approach estimates the confidence in the part match provided by an automated perception system, which is used to detect perception failures. Human intervention is also invoked if uncertainty in estimated part location and orientation leads to a singulation planning failure. We have developed a user interface that enables remote human interventions when necessary. Finally, if uncertainty in part posture in the gripper leads to failure in placing the part with the desired accuracy, sensor-less fine-positioning moves are used to correct the final placement errors. We have developed a fine-positioning planner with a suite of fine-motion strategies that offer different tradeoffs between completion time and postural accuracy at the destination. We report our observations from system characterization experiments with a dual-armed Baxter robot, equipped with a Ensenso three-dimensional camera, to perform bin-picking on mixed-bins.

1. Introduction

Bin-picking is a precursor to kitting [1,2] and assembly operations in many discrete-part manufacturing applications [3–5]. The use of robots for bin picking can enable handling a wide variety of parts without any change in the hardware; hence it offers a flexible automation solution. Machine vision is a key enabling technology in this context [6,7]. Robotic bin-picking, guided by vision and other sensor modalities, has been successfully demonstrated with a high degree of reliability for bins containing a single type of part with a relatively simple shape [8].

When bins are complex, the reliability of robotic bin picking operations is reduced. The complexity in bins might arise due to the presence of multiple different types of parts. Such bins are called mixed bins. Recognizing the desired part in a mixed bin and estimating its location is a much more challenging problem from the perception point of view. Unstructured, randomly distributed, mixed-bins make the perception problem challenging due to the following reasons: (1) parts may lie in widely different three dimensional (3D) postures and (2) parts may be either partially or completely occluded by other parts. The problem is compounded due to factors such as sensor noise, background clutter, shadows, complex reflectance properties, and poor lighting conditions.

The complexity of the bin might also increase because the parts present in the bin have complex shapes, and can only be removed by holding them at certain locations and moving them in certain directions. Uncertainty in part location and orientation estimates may lead to a failure when the robot tries to extract the part from the bin. The potential for part tangling, and occlusion of grasping surfaces, makes the planning problem challenging because of perception uncertainties.

The effect of perception uncertainty propagates through every stage of task execution including, part recognition and pose estimation, singulation, and positioning. This thereby impacts the overall system performance. For example, the detected part match may not correspond to the specified part. Uncertainty in pose estimation may lead to poor singulation plans, and thereby singulation failures. Finally, uncertainty in the initial grasped posture of the part may lead to errors in part posture at the destination after

* Corresponding author.
E-mail addresses: jeremy.marvel@nist.gov (J.A. Marvel), skgupta@usc.edu (S.K. Gupta).

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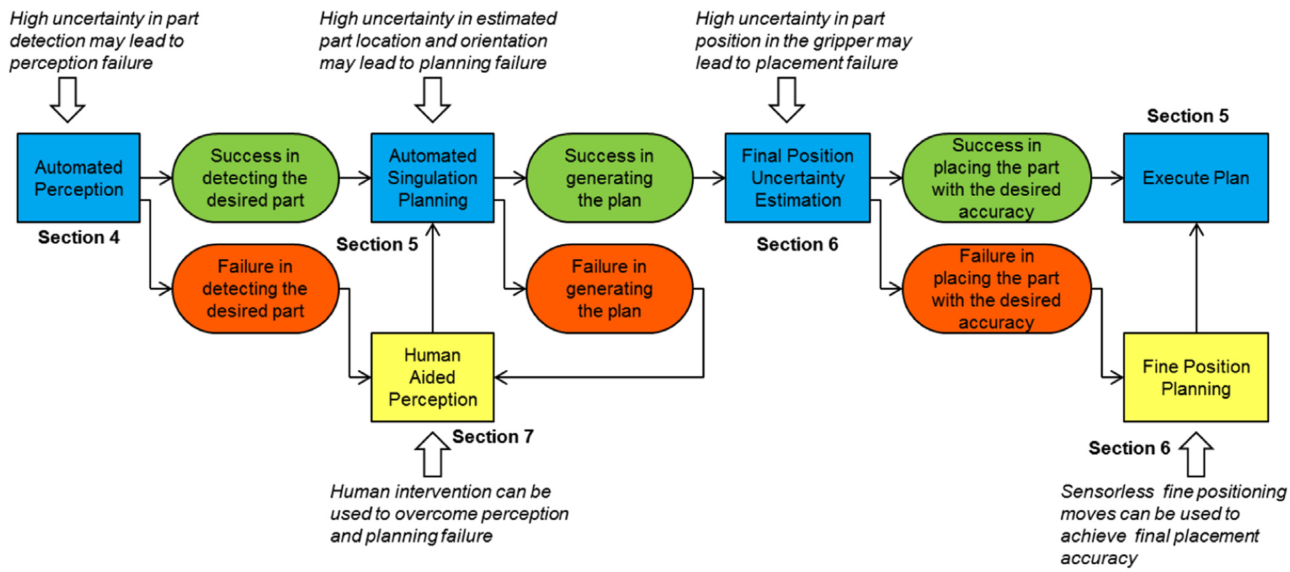

Fig. 1. Flowchart showing how uncertainty is handled at various stages of the bin-picking task.

final drop off. However, many manufacturing applications require parts to be placed in a specified posture, within tight tolerances, before tasks like assembly or packaging can take place [9].

To improve the reliability of the bin-picking operations, we need to characterize the effect of perception uncertainty on bin-picking task execution performance. We also need to develop methods to deal with situations when high perception uncertainty requires specialized methods to prevent the failure. In this paper, we present a comprehensive approach to handle perception uncertainty to reduce failure rates in unstructured robotic bin-picking. The main failure modes at various stages of the bin-picking task and methods to recover from them are shown in Fig. 1. We first characterize the uncertainty in estimating the six dimensional (6D) posture of a part match found by using an automated perception system. The input to the system is a CAD model of the part to be singulated and a 3D point cloud of the mixed-bin. The resulting uncertainty information is used to estimate confidence in part recognition and pose estimation. If perception uncertainty results in a part detection failure or singulation planning failure, then human intervention is invoked. We have developed a user interface that enables remote human interventions when necessary. Intervention in this context may correspond to the human finding a good part match and obtaining an improved estimate of the part pose by using appropriate controls present in the user interface. If perception uncertainty results in an unacceptable error in the final posture of the part at the destination, then fine positioning is invoked to achieve the desired postural accuracy. We have developed a fine-positioning planner to correct errors in the destination posture of the part arising due to uncertainty in the initial grasped state. We have developed a suite of fine-motion strategies that offer different tradeoffs between completion time and postural accuracy at the destination.

In our earlier works, we presented preliminary versions of automated perception algorithm [10], perception failure resolution using human intervention [11], singulation planning [12], and fine-positioning [13]. We treated each problem in an isolated manner. This paper significantly improves upon methods reported in our previous works and presents a comprehensive approach to identify and address perception-uncertainty-induced failure modes in robotic unstructured bin-picking.

2. Related work

Many research groups have addressed the problem of robotic bin-picking. Different aspects of robotic bin-picking include perception, grasp-planning, and motion planning. Each of these represents a vast area of research in itself. Therefore, we survey only prior research that integrated these aspects to achieve bin-picking or grasping. A summary of the focus of various works on bin-picking is shown in Table 1. In our survey, we also pay attention to whether uncertainty was taken into account, and if so, how it was handled at different stages of task execution. Most of the research in bin-picking considered the problem up to stage where the part is successfully picked from the bin, while ignoring the next stage of delivering the part in a known posture accurately at the destination. We survey the field of sensorless manipulation where this problem was treated separately.

2.1. Perception for robotic bin-picking

Most previous attempts on a systems approach to bin-picking mainly focussed on the perception problem [25,24,23,21,4,20,19,18,16,15,14], while assuming accurate robot grasping. However, model inaccuracies and sensor uncertainties make it difficult for a majority of the perception algorithms to provide reliable object recognition and localization estimates, thereby affecting overall bin-picking performance.

Except for a few, many of these methods ignored the evaluation of perception quality before proceeding to picking the part. Liu et al. [4] presented a directional, chamfer-matching-based, object localization and pose estimation in heavy clutter for robotic bin picking. The accuracy of their method was tested empirically by evaluating the consistency of a pose estimate across multiple viewpoints of the camera. This was achieved by placing an object in the scene, estimating its pose in local frames of different camera viewpoints, transforming them into the world frame, and plotting the histogram of deviations from the median pose estimate in 6D. But there was no mechanism in place to rate the perception result during task execution.

Papazov et al. [33] presented a 3D object-recognition and pose-estimation approach for grasping, based on geometric descriptors, hashing techniques, and random-sampling consensus (RANSAC)-like sampling strategies. The authors evaluated the quality of a recognition hypothesis by defining an acceptance function,