

Optimizing Object Placement for Human Support Robots Using a Two-dimensional Irregular Packing Algorithm for Efficient Tray Storage

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Abstract

Human support robots (HSR) are robots that assist humans in their daily tasks. Their main application is tidying up, which involves detecting objects, determining appropriate placement locations, and organizing them. This study focuses on tidying up tray storage. Determining suitable storage positions is essential for storing objects in the tray. If the robot store objects in fixed predetermined locations, it can lead to inefficient use of storage space, and in the worst case, objects might collide and overflow from the tray. To address this limitation, we propose a 2-dimensional irregular packing algorithm utilizing an object mask method to calculate the best placement location. This study evaluates the proposed packing algorithm against the standard method to determine which approach is more effective in HSR applications.

Keywords: Home service robot, 2-dimensional packing algorithm, Image processing, Object placements

1 Introduction

The growing of aging population and declining birthrate in Japan leads to an aging society. With significant labor shortages, to address these issues, automation, and robotics have gained attention due to their ability to operate effectively in various settings of tasks and environments.

Among these advancements, Human Support Robots (HSR) [1] have gained significant attention, with active research contributions including [2], [3], [4], [5], [6], [7] and [8]. HSR is designed to assist humans in their daily life and activities. One of its main applications is tidying up, where the robot detects objects, grasps objects, relocates objects to appropriate storage locations, and organizes them efficiently. For the tidying-up task, there are many target storage areas for objects such as boxes, drawers, shelves, and trays.

In this study, we focus on tray storage, where objects must be placed on a flat surface. In the case of storing

objects in boxes or drawers, fixing the placement positions enables high-speed storage operations. On the other hand, when storing objects on a tray, it is necessary to determine placement positions that prevent objects from falling off the tray while avoiding overlaps. If the spacing between placements is set uniformly regardless of the size of the objects the robot grasped, the tray's space utilization efficiency decreases. Moreover, it is essential to ensure no interference between the robot's hand and the objects already placed on the tray.

To overcome these limitations, we propose a two-dimensional irregular packing algorithm utilizing the actual shape of an object to calculate an optimal placement location for the robot to store objects in the tray. This method maximizes storage efficiency, enabling the robot to pack more objects into the tray. Furthermore, selecting objects in order of height from lowest to highest helps prevent collision and objects falling off the tray.

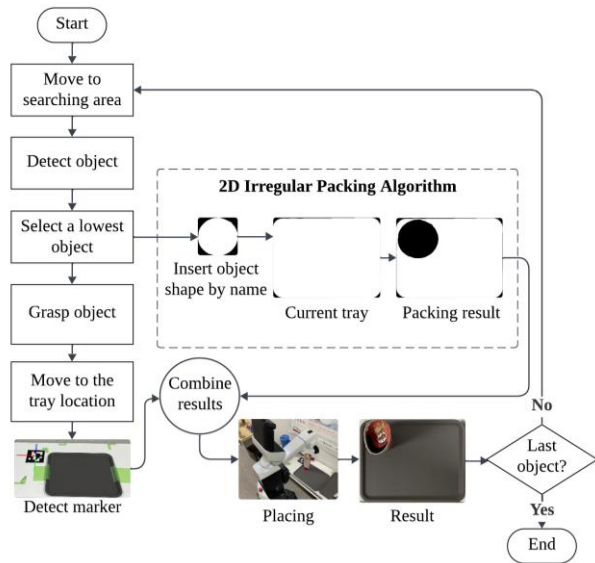


Fig. 1 Overview of proposed method

2 Methodology

2.1 Proposed Method

Fig. 1 is an overview of a proposed system that performs accurate tidying-up to the tray. The process begins by moving the robot to the searching area, then using You Only Look Once Version 8 [9] to detect and extract the object mask, object ID, position, orientation, and object name. Once the objects are identified, the system selects the objects with the lowest height, to prevent the hand collision with the neighborhood objects during the placement of the grasped object. Then, the robot determines a grasp point using the object mask and a depth image [10]. Simultaneously, the system executes a two-dimensional irregular packing algorithm after sorting and selecting the target object. This algorithm retrieves the object shape from the database to calculate the optimal placement location for the robot to maximize storage efficiency. The robot then moves to the tray location and detects an Aruco marker [11]. This marker is the reference point of the tray's position. The output of the packing algorithm is combined with the reference coordinate from the marker to determine the final placement location for the object. The robot then places the selected object at the calculated position on the tray. If there are remaining objects, the process repeats from the beginning to the next object.

2.2 Collecting Data

The proposed method utilizes the actual shape of the object to find the suitable position for placing. Fig. 2 shows the steps of collecting data, the steps of collecting data begin with capturing top-view images of objects by using a hand camera of HSR, with the 50 cm height

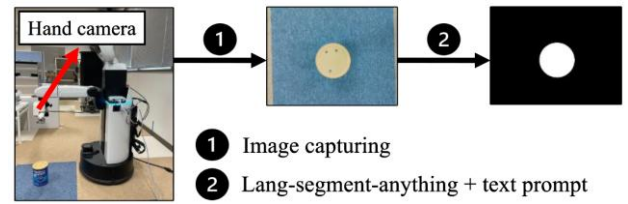


Fig. 2 Process of collecting data

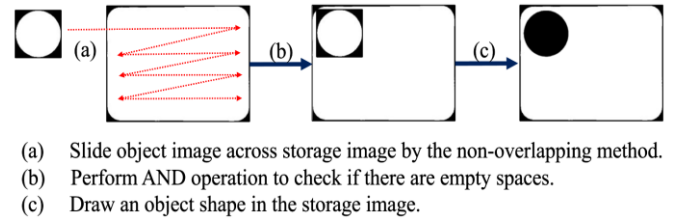


Fig. 3 Two-dimensional irregular packing algorithm

above the floor. Then Lang-Segment-Anything [12] is used to extract the object mask from the background using object description as a text prompt. After that, we convert the mask of the object to a binary image format and save it in the database for further use in the packing algorithm.

2.3 Two-Dimensional Irregular Packing Algorithm

Fig. 3 shows the proposed algorithm to find a suitable placement location. Step (a), we use the non-overlapping convolution method to slide masks across the image of the storage area. Step (b) performs a logical AND operation between a mask of objects and a storage image. If the result of the operation is the same as the image of an object that means this position is not overlaid with other objects. The last step involves using step (c) to draw an object's shape in the storage image. This allows the system to recognize that an object already exists in this position when packing the next objects.

3 Experiment

3.1 Experimental settings

Fig. 4 illustrates the map and environment utilized in experiments. The map consists of two main areas: the searching area and tray storage. The searching area is where the objects are taken, while tray storage is the location to place the objects. This study uses the objects from the YCB dataset [13] to conduct the experiments. The tray used to store the objects has dimension of 37 x 29 cm.

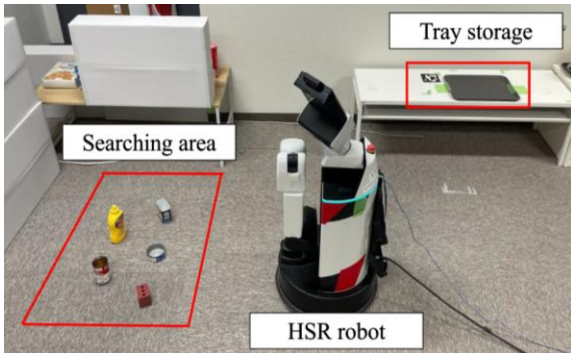


Fig. 4 Map and environment

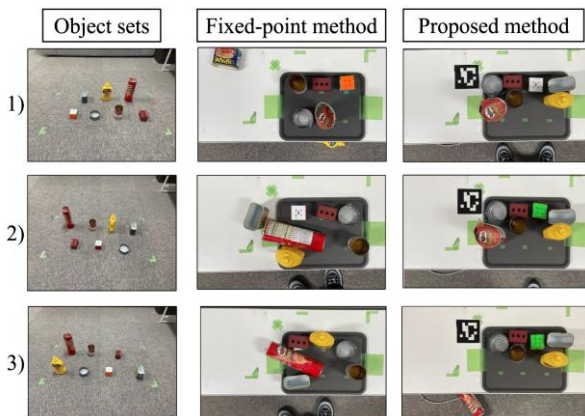


Fig. 5 The comparison result of proposed and fixed-point deposition method

3.2 Experiment I: Comparison between Proposed and Fixed-Point Deposition Method

In this experiment, we compared the proposed method with a fixed-point deposition method to evaluate the number of objects each method can store and the remaining usable space after completing the operation. The fixed-point deposition method sets placement positions at intervals that can accommodate the largest object. If the number of placements exceeds the predefined limit, the storage returned to the initial position to continue the placement.

As shown in Fig. 5, We evaluated each method three times using seven objects randomly positioned for each test. The number of objects that can be placed using the fixed-point deposition method is limited by the largest object in the dataset, with a maximum of six objects. Since there are seven objects in total, this method results in a collision, a fall from the tray, and no remaining usable space. For object grasping, this method selects the closest object, leading to different placement patterns across the three sets.

In contrast, our proposed method cloud stores seven objects and has a remaining usable space of around 40-50% of the tray. This demonstrated an efficient use of the tray storage space. By selecting objects in order of

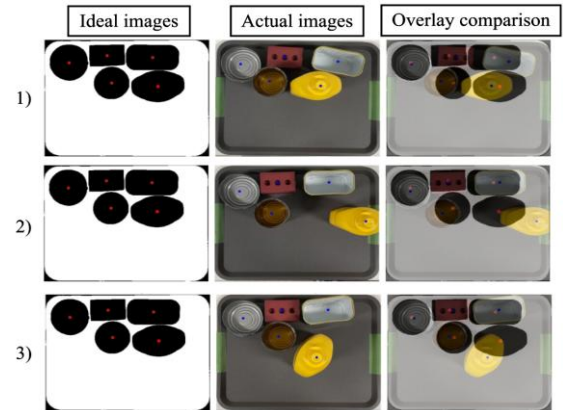


Fig. 6 Comparison between results from algorithm and actual placement

Table. 1 Shifted values between ideal and actual result

Set	Average distance [cm]
1	2.01
2	2.82
3	1.65

height from lowest to highest, the placement pattern remains consistent across all operations and helps prevent a collision by the robot hand.

3.3 Experiment II: Comparison between Ideal and Actual Placement Results

In this experiment, we compared the planned and actual placement results to evaluate the shifted distances between them. This distance was measured by calculating the displacement of the centroids between planned and actual locations along the x-axis and y-axis. These shifted values indicate the precision of the proposed method with the actual robot. We used five objects from the YCB dataset: Starkist tuna fish can, Foam brick, Spam potted meat can, Tomato soup can, and French mustard bottle.

Fig. 6 illustrates the comparison between the ideal result and the actual result of the proposed method. The left images represent the ideal placement locations generated by the packing algorithm with red dots or the centroids of each object. The middle images are the actual results of the robot operation with the blue dots as the centroids. The right images provide overlay comparisons to highlight the differences between the two results. Both result images were in the same dimensions.

Table. 1 summarizes the experimental result II, comparing the average Euclidean shifted distances of centroids between the ideal and actual results across three sets. Set 2 has the largest average Euclidean shifted distances (2.83 cm). In contrast, set 3 has the smallest average Euclidean shifted distances (1.65 cm).

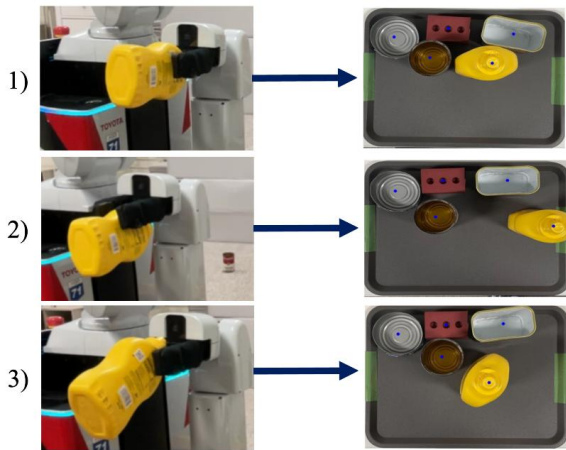


Fig. 7 Grasp position affects the placement result

4 Discussion

In experiment I, the proposed method demonstrated superior performance in optimizing space usage. On the other hand, this method has to place objects close together to optimize the usage area, if some objects are shifted, it can easily affect the other object. As shown in Fig. 5, the last object from set 3 fell off the tray because the first object was shifted downward. This shifted placement highlights the importance of precision in object placement for this method.

From experiment II, we can observe that some of the objects were shifted from the ideal position. This influences the placement results in the position of an object when the robot performs grasping. As shown in Fig. 7, the differences in grasping positions directly influence the placement results. For example, in the top image, we can get an accurate placement result when the object is grasped from the correct position. In the second case, the robot grasped the object shifted from the center of gravity, causing a shift in placement on the tray. Lastly, in the third case, the object's posture changes while the robot moves from the searching area to the tray location. The changes in posture, made the object not perpendicular to the tray surface, resulting in the object moving or shifting after releasing the object.

Even if the target coordinate point for place objects is correct, the grasping position affects the final placement result, and this emphasizes the importance of precise and stable grasping.

5 Conclusion and Future works

In this paper, we proposed a two-dimensional irregular packing algorithm that utilizes the object masks to determine the suitable placement position for the robot to store objects in tray storage. In experiment I, our proposed method is efficient by able to place all objects and have significantly more remaining space, compared to the fixed-point deposition method that can place only six objects. In experiment II, we used the HSR robot to

place objects and observe the shifted distance between the planned placement location and the actual placement location. The largest average Euclidean distance is 2.83 cm, and the smallest average Euclidean shifted distance is 1.65 cm.

For future works, we aim to enhance the proposed method by incorporating feedback mechanisms, observing actual packing, and comparing it with the ideal packing, and then adjusting the actual packing by the robot to be close to the ideal packing. Also grasping position can directly impact the placement outcome, we will focus on enhancing the grasp pose estimation to achieve precise and stable grasping.

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