# Automated Robot Picking System for E-Commerce Fulfillment Warehouse Application



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# Automated Robot Picking System for E-Commerce Fulfillment Warehouse Application

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**Abstract**: *In e-commerce fulfillment warehouses, manual item picking is a labor-intensive and tedious task. Therefore, automation of item picking can improve efficiency and save cost for e-commerce businesses. This paper presents an automated robot picking solution that meets the requirements of automating the picking of items from shelves. The hardware of the proposed system comprises a lightweight robot manipulator, a low-cost commercially available 3D camera system and a custom-built robotic gripper. The software of the proposed system is modular comprising the task planning module, item identification and registration modules, grasp planning module and the motion planning modules. Simulations are carried to illustrate full cycles of the automated picking of items. Experiments were conducted using a prototype of the proposed system. The test results show the system is capable of picking several regularly-shaped and irregularly-shaped items from the bins of the shelf. Such preliminary observations prove the system to be flexible and versatile. It has the potential to be used in real e-commerce fulfillment warehouses.*

**Keywords: Pick-and-place, E-commerce fulfillment warehouse, Item recognition, Item grasping, Task planning, Motion planning**

## I. Introduction

In recent years, e-commerce has been revolutionizing the business world. The global sales of e-commerce businesses are growing at an annual rate of 16% between 2001 and 2010 [1], [2]. Several e-commerce businesses like Amazon, Alibaba and JD.com are doing well. These businesses have changed the way we shop. They receive millions of online orders daily. The orders may comprise multiple items of different sizes and the customers expect to receive their orders within 24 hours. Therefore, order fulfillment is a time consuming and time-critical operation of e-commerce. Moreover, there is an ongoing demand to be more responsiveness to the customers. Thus, automation is the key technology enabler in order fulfillment [3].

A lot of research and development activities are seen on the deployment of robotic technologies in e-commerce applications. In year 2013, Amazon introduced an automated delivery system known as Amazon Prime Air. This new service uses miniature unmanned air vehicles (MUAVs) to deliver packages to the customers in less than 30 minutes [4]. Google has also launched their "project wing" in Australia [5].

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There are also robots working in fulfillment warehouses. Amazon has deployed Kiva robots in several of their fulfillment warehouses [6]. A Kiva robot moves the shelving units from a storage location to a location where the ordered items will be picked manually and then returns the shelving units to a storage location. The Kiva robots are able to work continuously and more efficiently than its human counterparts [7], [8]. Swisslog is another company that provides mobile robots to e-commerce fulfillment centers [3]. These mobile robots move the shelving units to the human pickers. The items are manually picked from the shelves and put into the boxes for shipping to the customers. Many human pickers are employed to pick items from the shelves. This labor-intensive and time-critical task can be automated to improve efficiency and save costs for the e-commerce businesses.

In this paper, an autonomous pick-and-place robotic system is presented. The proposed system is developed to automate tedious task of picking items from shelves. The rest of this paper is organized as follows: In Section 2, several design requirements are proposed after analyzing the operation characteristics of an e-commerce fulfillment warehouse. System hardware architecture and prototype is described in Section 3. In Section 4, the control software is designed using a distributed and modular architecture and the operation logic of a full cycle of item picking is illustrated. In Section 5, simulations are carried out to evaluate feasibility of developed software system. In Section 6, experiments are carried out using the prototype system. The experiment results show the feasibility of system design and its practical operation performances.

## II. Warehouse Items Picking Analysis

Fig.1 shows items manually picked from the shelves in an e-commerce fulfillment warehouse. Each shelf can have up to 10 items packed tightly together. A human picker should be able to identify the items ordered by the customers, pick it out of the bin, scan the barcode for verification and put the items into an order bin in a short amount of time.

Fig. 1. A warehouse associate picks items from a shelf [6]

Automated pick-and-place of items is one of the most common tasks for robot arms. Such robotic systems are used in the food and medical industries, electronics manufacturing industry and service robotics [9]. In traditional industrial applications of pick-and-place robot, the motion trajectory is normally pre-programmed. This kind of system is usually developed for quick and repetitive picking of items with similar geometry and weights. The main design considerations are picking velocity and payload capability of the robot. Furthermore, most of these robotics pick-and-place applications assume the availability of a complete 3D model of the picked objects [10], [11], and [12].

Due to its difference in operation characteristics from traditional robot picking applications, there are several challenges for developing an automated robot picking system for e-commerce fulfillment warehouses. The first challenge is the wide variety of products in typical e-commerce fulfillment warehouses. While many items like books and DVDs are regularly shaped, there are also irregularly shaped items like stuffed toys, children's necklaces, vacuum-packed items and USB sticks. A versatile robot gripper with a flexible manipulation algorithm and optimized task planning are required for addressing such challenges. The second challenge is the complex geometry of both the environment and grasped objects. It is often difficult for a pick-and-place robot to automatically plan its motion [13], [14].

Therefore, several design requirements are proposed to address the above-mentioned challenges.

1) In an e-commerce fulfillment warehouse, the movement of products is often crossing path with human workers. Moving products in such environments remains a challenge for existing robots. Safety is the first critical issue to be concerned with. Therefore, human-friendly lightweight robot with human robot interaction capability should be used.

2) E-commerce business is a very fast moving customer-oriented business. Different services are needed for meeting different customers' requirements. To keep up with the high volume of daily orders, the robot picking system should be versatile and adaptable.

3) To pick an item from a bin of the shelf, the robot may interact with the shelf, the items in the bin and other human workers. Hence, the work-cell of the robot is complex and cluttered. Therefore, the robot must be able to avoid colliding with obstacles in real time.

4) Picking, packing and shipping are the three major tasks that are always performed in a fulfillment center. To avoid mistakes and delays in the fulfillment of customer's orders, these three tasks have to be performed efficiently and accurately. Therefore, the robot must be able to identify and pick the correct items from the bin and put them into the order bin in reasonable amount of time.

To meet these requirements and challenges, this paper proposes an automated robot picking system. The following sections will describe design details of the whole system.

## III. Description of the Hardware Architecture

The design of the autonomous pick-and-place robotic system comprises the hardware and software components. The proposed hardware architecture is illustrated in Fig. 2. It has the following components:

1) The UR5 is a lightweight robot manipulator with intrinsic safety mechanism. It is a human-friendly, torque-controlled robot manipulator with a maximum payload of five kilogram. It has a spherical workspace and a maximum reach of 850 mm [15].

2) Two low-cost commercial 3D Kinect cameras. One of the Kinect sensors is mounted on the robot end-effector, which captures RGB images and depth information of the objects in the shelf bin. Registration and recognition algorithms are developed for obtaining 6 DOF pose of the items in the target bin. The other Kinect sensor is used to capture surrounding environment of the robot for obstacle avoidance and human interaction safety purposes.

3) A customized robot gripper is designed for grasping different items from the bins of the shelf.

4) An air compressor and several pneumatic vacuum components, which provide grasping forces for robot grippers.

5) A standard desktop PC with Ubuntu 12.04 Linux OS installed which hosts the control software. It communicates with the UR5 robot controller via TCP/IP protocol in a 10ms control cycle.

Fig. 3 shows the developed prototype of the automated pick-and-place robot system in the laboratory.

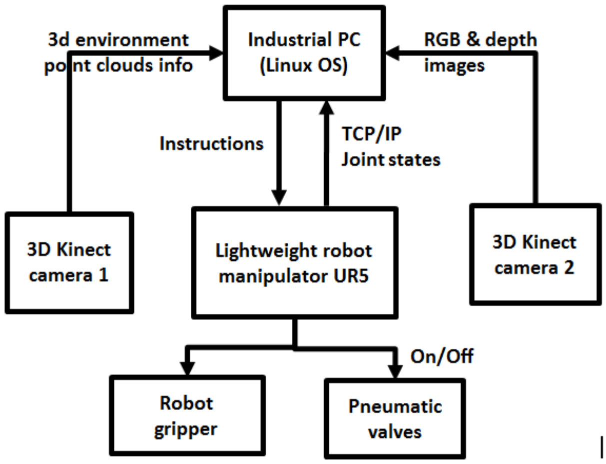


Fig. 2. A scheme of the system architecture

Fig. 3. A prototype of robotic pick-and-place system

## IV. Software Modules and Operational Logic

Control software running in the standard desktop PC is developed on ROS (Robot Operating System) where the modules communicate using the publish-subscribe mechanism [16]. In addition, several packages from ROS-Industrial stacks are used for communicating with the UR5 robot via the TCP/IP communication protocol [17]. Such communication interface makes it suitable for controlling and coordinating multiple robots. Fig. 4 shows a scheme of the software modules of the robotic pick-and-place solution. It consists of the six modules described in the following paragraphs.

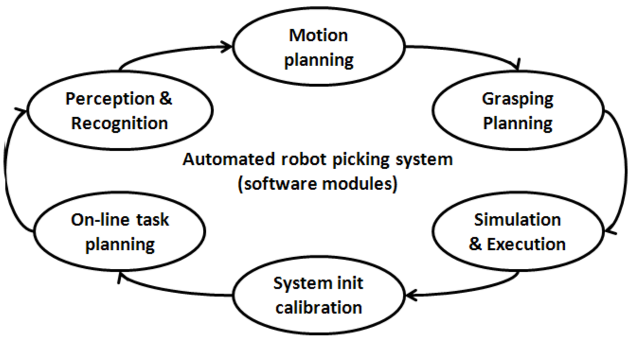


Fig. 3 Scheme for the developed software modules

1) The initialization and calibration module is responsible for calibrating the motion control module to the position of the robot. This is necessary to ensure a precise positioning and grasping of the item as well as for the acquisition of 3D images. In particular, an automated calibration method has been used to significantly reduce system setup time.

2) The task planning module is responsible for setting the initial picking sequence of target items according to a JSON file generated based on the customer's order. It optimizes the picking operation by considering the confidence values returned from the vision and grasping modules. In addition, it performs error recovery of the items missed during the actual picking operation.

3) The identification and registration module is used to distinguish different items by indexing and comparing with the RGB images of the registered items in a library. Position and orientation information of the target items are sent to motion planning module after a successful registration.

4) The motion planning module is responsible for generating real-time obstacle avoidance trajectories for the lightweight robotic manipulator. It moves the UR5 robot to the bins where the target items are picked and then moves it to the position where the picked target items can be deposited.

5) The grasp planning module deals with the dynamic grasping strategy for grasping different target items. It is designed to grasp target items of different shapes, sizes and materials. It uses information from the registration module to decide on how the target items should be grasped.

6) The simulation & execution module is responsible for simulating the entire set-up. Simulation with real streaming sensor data can save a lot of testing time. Motion execution module is mainly composed of robot hardware drivers and communication API functions for 3D cameras and other devices.

Fig. 5 shows a detailed diagram of the software modules of the autonomous pick-and-place robotic system. All software modules are managed by a program manager, which is a cluster of ROS launch files, YAML files for system parameters configuration and python and C++ host programs. The program manager invokes the other modules by calling services and actions. Other modules are developed as client nodes for providing services to the program manager.

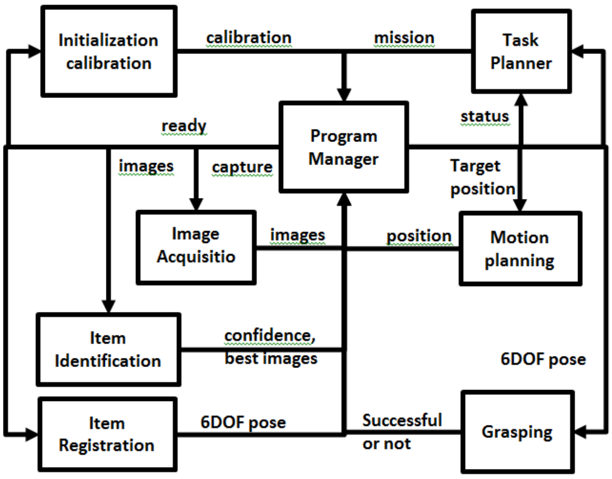


Fig. 4. The operation logic of software modules

As indicated in Fig. 5, a typical operation sequence can be described in the following steps.

Step 1: The initialization and calibration module begins by performing a quick automated calibration algorithm as proposed in [18]. This module calibrates the robot and 3D cameras. Point cloud data obtained from a Kinect sensor helps to build an environment of the work-cell, which is used by the motion planning module to generate obstacle avoidance motion trajectories.

Step 2: A pre-generated JSON file includes a list of ordered items from customer and also item storage information in the shelf. This JSON file is sent to the task planning module for deciding on the optimized picking sequence.

Step 3: A collision avoidance motion trajectory is generated and the robot manipulator moves until the gripper approaches the target bin.

Step 4: Once the gripper is in front of the target bin, a 3D stereo camera mounted on the robot end-effector captures several RGB images from different orientation angles.

Step 5: The captured images are sent to the identification module. An algorithm compares the captured images with the pre-registered images stored in a library. This module is capable of identifying the target item very quickly. After the item is identified, the program proceeds to step 6, otherwise goes back to step 4 to capture another image.

Step 6: Once the target item is identified successfully, depth information and point clouds data of the target item will be obtained. In the registration module, position and orientation information of the target item are computed, as well as the confidence values which helps the task planning module to decide if the UR5 robot should proceed with the picking of the target item or to just temporarily abort picking the target item.

Step 7: Once a high confidence value is obtained, robot gripper begins to grasp the target item. Using one of the many grasping strategies, the identified target item can be grasped successfully at a certain confidence level.

Step 8: The tactile sensors give information whether an object is successfully grasped. The UR5 robot moves the grasped item and deposits it into the order box. Finally, the robot manipulator goes back to a home position to wait for the next picking task.

### V. Simulation

A simulation module has also been developed. It is used to test developed control algorithms and evaluate overall operation performances of the software modules. It is also useful for developing the task planning algorithms to find a group of weight parameters for an optimized picking sequence. Furthermore, by combing with the real streaming data from 3D Kinect cameras, robustness of the developed motion planning algorithms can be tested using a simulated model of the UR5 robot.

Fig. 6 shows a snapshot of the simulation environment for the autonomous pick-and-place robotic system. The simulation environment is built on Rviz along with CAD files of the UR5 robot, the robot stand and the shelf imported using URDF (unified robot description format) files as indicated in the figure with the same geometry sizes of physical objects. By using Moveit! Setup assistant, collision checking between each link, chain groups for motion planning can be configured. Thus, real-time collision avoidance motion trajectories for the robot manipulator can be generated by invoking the relevant API [19]. An industrial robot simulator provided in ROS-Industrial package is used to simulate the motion of the robot.

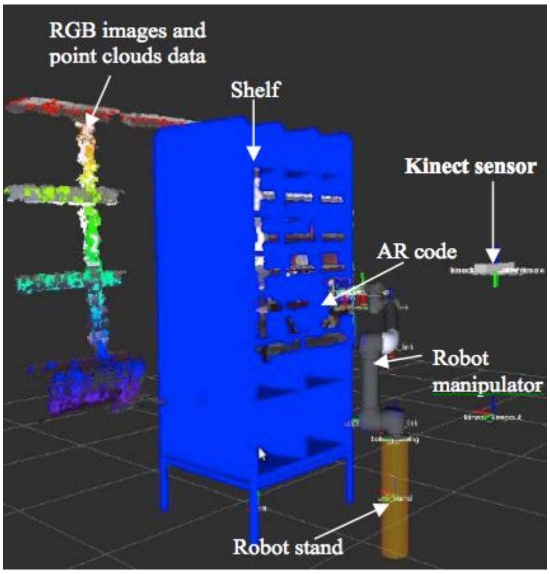


Fig. 6. A snapshot of simulation environment developed in Rviz

It can be noted from Fig.6 that RGB images and point clouds data are streamed from the actual 3D Kinect sensors. Since Rviz is an environment solely for kinematic simulation and sensor data visualization, dynamic object grasping procedure cannot be simulated, which is quite challenging and was not considered in this paper. However, Gazebo is a dynamic simulation environment that can be easily integrated for the next part of the work. In order to simulate the item picking procedure, a virtual box is attached to the gripper when a successful item picking event occurs. Fig. 7 shows snapshots of the simulation.

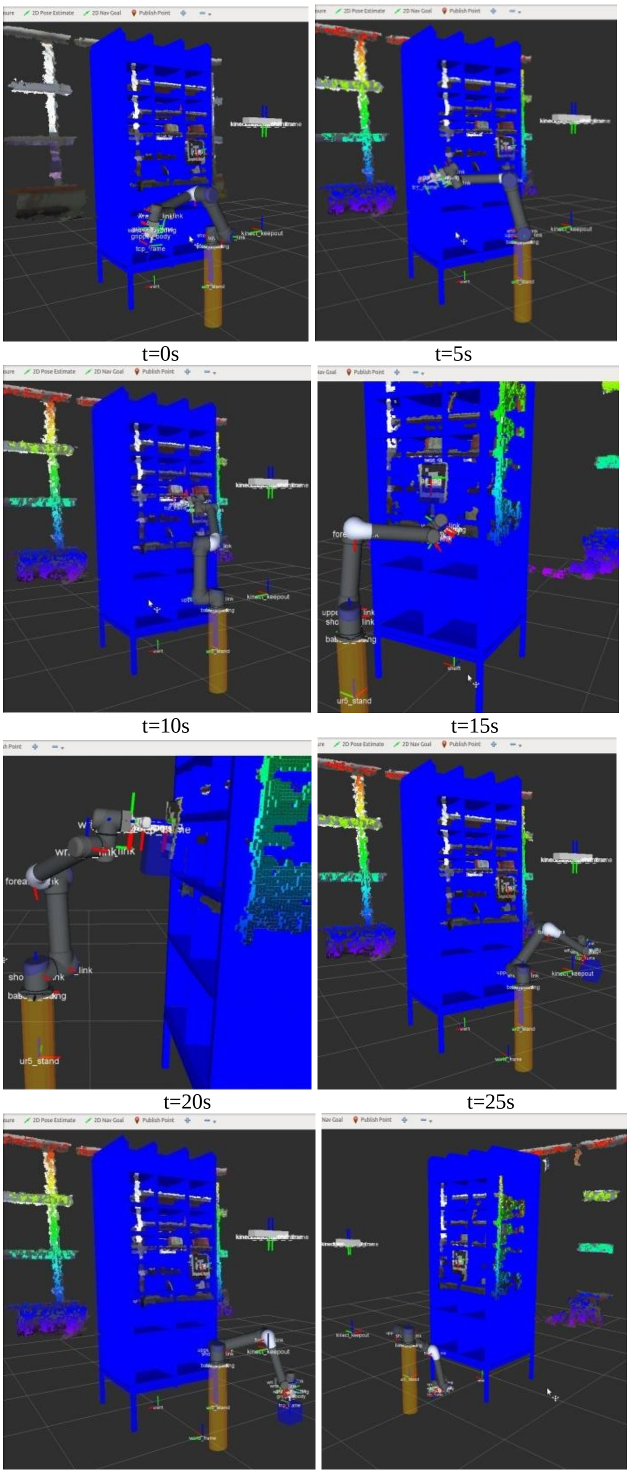


Fig. 7 Snapshots of the simulated robot bin-picking movements

A full cycle of simulation takes about 35 seconds to perform a full cycle of picking a target item from a bin. Snapshots of the simulation are shown at 5 seconds interval. Seen in the simulation, an AR code is put in front of a bin to test item tracking capability of the relevant software modules.

As shown in Fig. 7, the UR5 robot manipulator moves to a pre-defined home position. This is where the position and orientation angles of the target AR code are computed. The robot manipulator reaches the target position, grasps the virtual box and moves it to the order box while avoiding collision with obstacles. Finally, the robot manipulator returns to the home position.

## VI. Experiment

Experimental tests are carried out to evaluate the performance of a prototype of the proposed autonomous pick-and-place robotic system. Fig. 8 shows an RGB image obtained from the Kinect sensor mounted on the robot end-effector. For this experiment, the UR5 robot is tasked to pick the yellow-duck-bath-toy in bin C, school-glue and black-warrior in bin E.


Fig. 8 Captured RGB image and required picking items in the bin

Fig. 9(a) shows a mask image generated from the image acquisition module illustrated in Fig. 5. This mask image helps to segment target items from their surrounding background. Fig. 9(b) shows a depth image obtained from the item identification module. In the item registration module, depth image and points cloud data are obtained to compute the pose of the target item. This information is used by the grasping module to decide and choose a proper grasping strategy for the picking the target item.

(a) (b)

Fig. 9 A mask image and a depth image in the perception module

In the experimental tests, the robot picking system is able to pick an object in every cycle. On average, it is estimated that the robot picking system needs about 45 seconds for a single item picking, which comprises a full sequences of object detection and recognition, approaching, grasping, retracting, placing the grasped target item into an order box and moving the UR5 robot back to the home position. Fig. 10 shows the snapshots of the robot picking a yellow-duck-bath-toy from the shelf at 5 seconds interval.

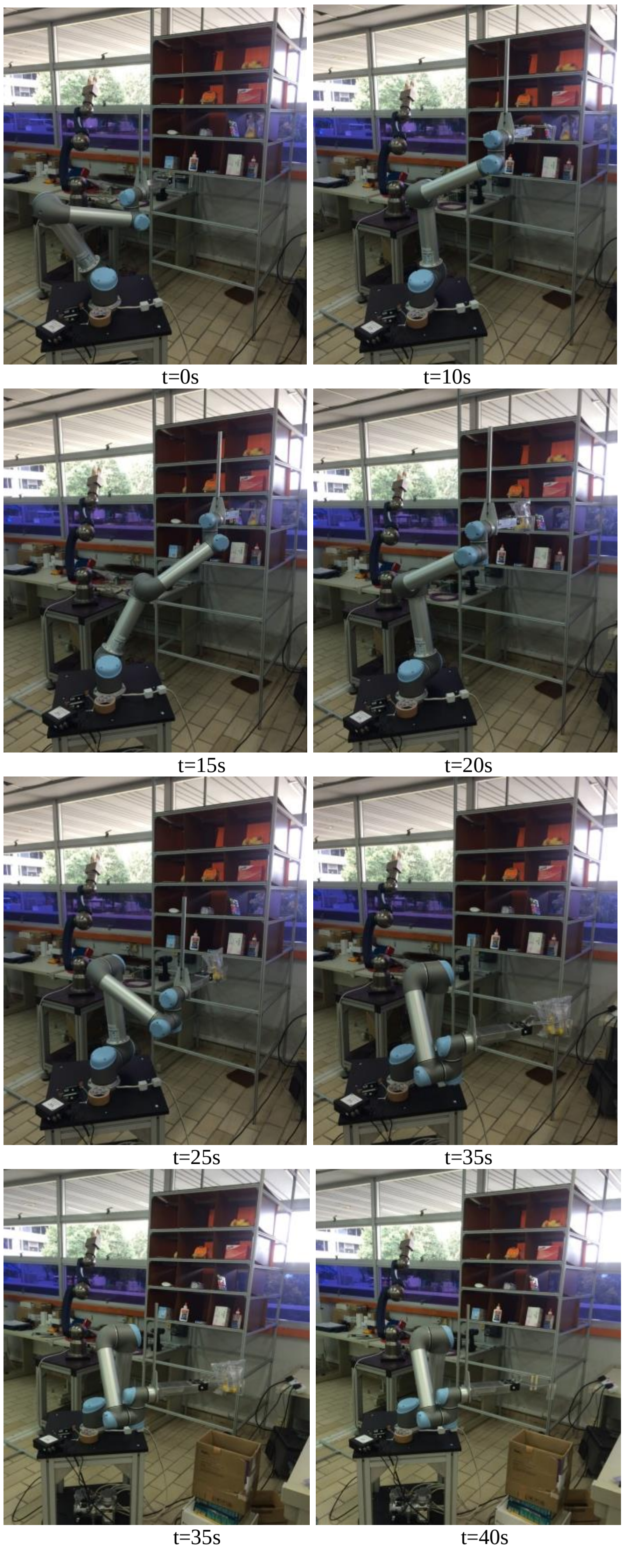


Fig. 10 Experiment snapshots of the robot picking an object

Fig. 11 shows a close view from the Kinect sensor that is mounted on the robot end-effector, which illustrates the robot gripper picking sequences. The robot gripper has two fingers and each finger is a four bar linkage mechanism. Fingers are actuated by two position and force controlled servo motors. It is a simple robot gripper capable of grasping different items with dimension range from 150 mm to 20 mm.

The experiments demonstrate how the proposed autonomous pick-and-place robotic system is used. These results could only be achieved due to the fault tolerance capabilities of the system during the entire process, which is handled by the task planning sub-module.

Fig. 11 Close view of the robot gripper picking sequence

## VII. Conclusions

In this paper, an autonomous pick-and-place robotic system is presented. It is built to perform the tedious task of picking items in e-commerce fulfillment warehouses. The proposed robotic system comprises a lightweight robot manipulator, stereo cameras and other devices combined with their corresponding software modules. The software system is built using the modular approach. The logical operation of the software modules is briefly described. The system is first tested in a simulation environment using real 3D sensor data. Experimental tests are carried out using a prototype of the proposed robotic system. The test results show the proposed robotic system to be flexible and robust enough for picking different regularly-shaped grocery products. This ability to pick up regularly-shaped represents a first step toward a larger goal of picking up wider variety of items seen in e-commerce fulfillment warehouses. In future work, advanced perception algorithms will be developed; impedance control will be used for picking objects with different sizes and weights. New versatile grippers will also be built to improve the grasping capability.


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