Robotic Grasping and Manipulation Competition: Task Pool

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Abstract. A Robot Grasping and Manipulation Competition was held during IROS 2016. The competition provided a common set of robot tasks for researchers focused on the application of robot systems to compare the performance of hand designs as well as autonomous grasping and manipulation solutions. Tracks one and two of the competition were supported by tasks chosen from a predefined pool of tasks. This task pool was assembled by the authors based on the challenges faced in developing robot systems that have the flexibility to grasp and manipulate a wide range of object geometries. This paper provides an overview of the task pool as well as the selection of tasks to support the various stages of the competition.

Keywords: robot, grasping, manipulation, competition

1   Introduction

The first Robot Grasping and Manipulation Competition, held during the 2016 International Conference on Intelligent Robots and Systems (IROS) in Daejeon, South Korea, was sponsored by the Institute of Electrical and Electronics Engineers (IEEE) Robotic and Automation Society (RAS) Technical Committee (TC) on Robotic Hands Grasping and Manipulation (RHGM) [1]. The goal of the competition was to bring together researchers to benchmark the performance of autonomous grasping and manipulation solutions across a variety of application spaces including service, health care, and manufacturing robotics. This competition was the first of a planned series in the area of grasping and manipulation. It was designed to evaluate the performance of robot solutions that include grasp planning, end-effector design, perception, and manipulation control.

The competition was comprised of three tracks; (1) hand-in-hand grasping, (2) fully autonomous grasping and manipulation, and (3) simulation. This chapter presents the task pool used to support tracks one and two which incorporated 18 predefined manipulation tasks and 20 objects that were readily obtainable through on-line retailers. In order to help teams prepare their systems for the competitions, the rules along with 10 randomly chosen tasks and associated objects were provided prior to the competition. A competition task set was selected from the pool and provided to teams just prior to the competition. This task pool was developed by the authors based on the challenges faced in developing robot systems that have the flexibility to grasp and manipulate a wide range of object geometries across diverse application spaces. The task sets were selected to support the various stages of the competition based on tasks used in previous manipulation data collections [2], with emphasis placed on the physically interactive requirements in those manipulations [3, 4]. The objects in the tasks were designed to use items from the Yale-Carnegie Mellon-Berkeley (YCB) Object and Model Set [5] and the 2015 Amazon Picking Challenge (APC2015) [6] object datasets [1]. This paper provides an overview of the task pool as well as the selection of tasks to support the various stages of the competition.

2   Task Designs

Eighteen competition tasks were designed and separated into four levels of difficulties. For the competition, the possible points awarded were commensurate with the level of difficulty of the tasks. A task in level 1 is worth 10 points, a task in level 2 is worth 20 points, a task in level 3 is worth 30 points, and a task in level 4 is worth 40 points.

2.1   Pick Up Peas with a Spoon (Level 1 - 10 points)

Items

1. Twenty green peas
2. Spoon, bowl, plate and cup (Figure 1)

Setup

1. A 15.2 cm (6 in) bowl is half-full with green peas on Table (Figure 2)
2. A 25.4 cm (10 in) plate is located 25.4 cm (10 in) to the right of the bowl
3. A spoon is placed in a cup with the spoons handle out. The location of the cup can be defined by the contestants

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[1] Certain commercial entities and items are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Steps

1. The robot system grasps the spoon from the cup
2. The robot system uses the spoon to pick up peas from the bowl
3. The robot system uses the spoon to transfer the peas to the plate
4. Repeat steps 1 to 3 as needed

Rules and Scoring

1. Successfully transferring each pea is worth 2 points until reaching 10 points
2. The competition is terminated if the robot knocks over any object
3. Dropping peas outside of the plate is allowed

Fig. 1. Kit used for competition includes cups, bowls, plates and eating utensils .

2.2 Grasp a towel on the table and hang it onto a support (Level 1 - 10 Points)

Items

1. Towel
2. Towel hanger

Setup

1. A towel is placed flat on the table
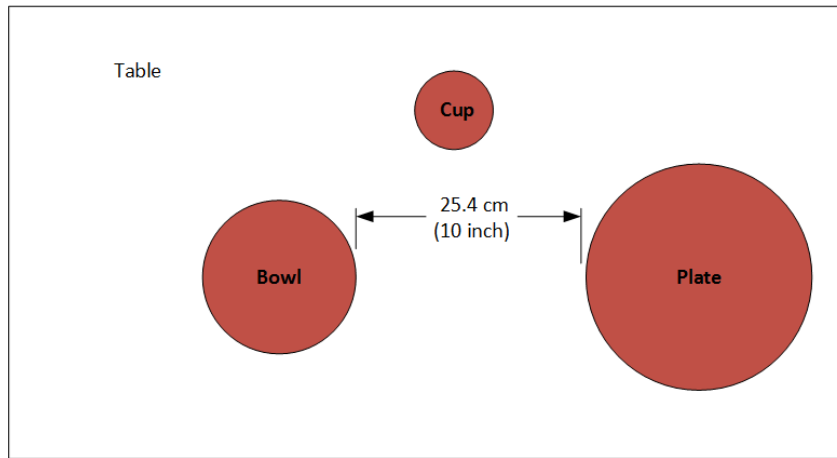2. A towel hanger is placed on the table 20 cm away from the towel

Fig. 2. A half-full bowl with peas and an empty plate and a cup are placed on a table
.

Steps

1. The robot system picks up the towel from the table
2. The robot system places the towel on the hanger

Rules and Scoring

1. The competition is terminated if the towel hanger falls
2. Ten points are received if the towel is placed on the hanger
3. Three tries are allowed
4. If the towel falls off the hanger the try is counted as a failure

2.3   Use a spoon to stir water in a cup (Level 1 - 10 Points)

Items

1. Spoon
2. Cup

Setup

1. A cup is placed on a table
2. A spoon is placed in a cup with the spoon's handle out
3. The location of the cup holding the spoon can be defined by the contestants

Steps

1. The robot system picks up the spoon in the empty cup
2. The robot system submerges the bowl of the spoon in the other cup half-full
   of water
3. The robot system stirs water using the bowl of the spoon for two cycles

Rules and Scoring

1. Five points for each of the two stir cycles completed
2. The competition is terminated if the cup is tipped over
3. Three point reduction if any water is spilled

2.4 Shake out salt from a salt shaker to a defined location (Level 1 - 10 points)

Items

1. Salt shaker
2. Salt
3. Measuring cup (1 L or 4 cup capacity)

Setup

1. Salt shaker is filled to approximately 90 % capacity with salt
2. Salt shaker is placed upright on table surface
3. The contestant can decide the location of the plate

Steps

1. The robot system performs grasp of salt shaker
2. The robot system shakes salt shaker above the plate with the salt shaker remaining completely intact during the task

Rules and Scoring

1. Dispensing 14.8 mL (1/16 cup) of salt on the plate earns full points
2. The salt on the plate will be poured into the measuring cup to measure
3. Salt is allowed to be dispensed outside of the plate but will not be included in the measurements
4. The salt shaker must remain intact during the entire test (teams are not allowed to take it apart)
5. Dropping shaker is allowed. However, if the robot cannot pick it back up, the competition is terminated

2.5 Use a brush to brush-off sand (Level 1 - 10 points)

Items

1. A flat piece of cardboard measuring approximately 50.8 cm x 50.8 cm (20 in x 20 in)
2. Plate as in Task 1
3. Cleaning Brush
4. Sand
5. Measuring cup (1 L or 4 cup capacity)

Setup

1. Cut hole in cardboard center slightly smaller than plate diameter and place cardboard centered on plate rim
2. Support the cardboard on table top so the plate clears table top
3. Spread 2 cups of sand evenly on tray surface keeping sand approximately 5.1 cm (2 in) from the plate

Steps

1. The robot system grasps the brush
2. The robot system uses the brush to sweep sand from tray surface into the plate

Rules and Scoring

1. Scoring is based on the amount of sand brushed into the plate, as measured in the measuring cup
2. Two points are awarded for each 30 mL (1/8 cup), with a maximum score of 10 points

2.6 Pick up items from a shopping basket and put them into an open plastic shopping bag (Level 1 - 10 points)

Items

1. Shopping Basket
2. YCB food item: Coffee Can
3. YCB food item: Box of sugar
4. YCB Food item: Potted meat can
5. YCB food item: Mustard Container
6. YCB food item: Plastic fruits
7. Plastic shopping bags
8. Wood suit hanger

Setup

1. Fix the shopping basket, and put all five items randomly into the shopping basket (all items with a random poses, as natural as shopping by human)
2. Mount the plastic shopping bag using wood suit hanger, to keep the bag open
3. Find and pick up the coffee can and put into the shopping bag
4. Find and pick up a box of sugar and put into the shopping bag
5. Find and pick up the potted meat can and put into the shopping bag
6. Find and pick up the mustard container and put into the shopping bag
7. Find and pick up the fruits and put into the shopping bag

Steps

1. The robot system localizes an object
2. The robot system grasps an object
3. The robot system transfers the object to a shopping bag
4. Repeat for each of the five items

Rules and Scoring

1. Successful transfer of each of the five items for two points for a total of ten points

2.7   Grasp a plug and insert it into a socket (Level 2 - 20 Points)

Items

1. Power Strip (w/ 2 alternating current (AC) outlets and 4 universal serial bus (USB) charging ports)
2. Industrial VELCRO adhesive backed
3. One AC night light
4. One USB night light

Setup

1. Mount the power strip to a surface using the VELCRO tape and plug into an AC power source
2. Plug one AC night light into one outlet of the power strip
3. Plug one USB light into one USB port of the power strip

Steps

1. The robot system extracts a light completely from the outlet. (If plug cannot be removed, consider loosening the plug for extraction in order to proceed to the next step)
2. The robot system plugs a light into the sockets to minimum depth for electrical contact (the light turns on)
3. Repeat for each of the two lights

Rules and Scoring

1. Five points awarded extract per light
2. Five point awarded insertion (light on) per light
3. No points awarded if the plug is manually loosened for extraction
4. No points awarded if the light doesn't turn on for insertion

2.8   Hammer a nail (Level 2 - 20 points)

Items

1. Smooth Foam approx. 5 cm x 10 cm x 30 cm (2 in 4 x ins x 12 in)
2. Five 10D 3-Inch Common Nails (or metric equivalent)
3. YCB hammer

Setup

1. Set hammer at predefined table location with handle overhanging table
2. Fix smooth foam to table top at defined location with the 5 cm x 30 cm surface on table
3. Mark nail locations on foam as shown in Figure 3
4. Mark nails with a 2.5 cm (1 in) and 5.1 cm (2 in) depth
5. Set nail in next location per test push to 2.5 cm (1 in) depth

Steps

1. The robot system grasps hammer at predefined location
2. The robot system positions the hammer at nail location and drives the nail
3. Repeat for four nails

Rules and Scoring

1. Drive nail with hammer to 5.1 cm (1 in) depth for two points per nail
2. Or drive nail to full depth (head flush with foam) for five points per nail

2.9   Grasp and cleanly tear away piece of toilet paper (Level 2 - 20 points)

Items

1. Toilet paper roll holder
2. Bath Tissue

Setup

1. Mount the roll holder on the edge of the table
2. Place a full roll of toilet paper on the roll holder with the roll parallel to the ground
3. Leave a small amount of paper hanging down

Steps

1. The robot holds on the loose toilet paper
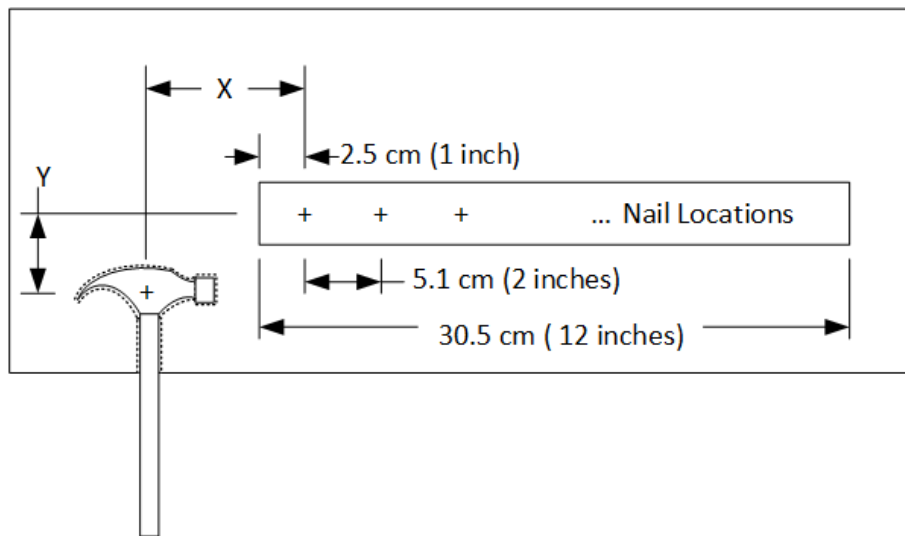2. The robot tears off a sheet of toilet paper in perforated squares

Fig. 3. Hammer a nail setup

Rules and Scoring

1. 20 points are earned to remove single square of toilet paper
2. The robot is allowed to try five times

2.10   Transfer straw into a to-go cup with lid (Level 2 - 20 points

Items

1. Straws
2. Cup with lid
3. A cup to hold straws

Setup

1. Several straws are placed into one upright cup
2. Another cup has a lid on it, placed upright and 30 cm to the side of the cup holding straws
3. The cup with lid is full of water

Steps

1. The robot system picks up one straw from the cup of straws
2. The robot system places the straw into the straw hole while keeping the cup upright

Rules and Scoring

1. The location of the cup can be defined by the contestant
2. 20 points are earned for successful insertion with cup remaining upright
3. The competition is terminated if the cup with lid is tipped
4. Dropping straws is allowed

2.11   Pick up and place using tongs - Level 2 - 20 points

Items

1. Forceps (tongs)
2. Five objects

Setup

1. Tongs placed on planar surface
2. Define goal placement zone with a 5 cm radius circle
3. Each of five objects presented to contestant for self placement 20 cm from defined goal zone

Steps

1. The robotic system grasps the tongs
2. The robotic system uses the tongs to pick up objects and relocate into the goal zone
3. Repeat for each object

Rules and Scoring

1. One point for grasping and lifting the tongs
2. One point for each object grasped and lifted above the plane
3. Two points for successful transfer of each object into the goal zone
4. Only the tongs can contact each object
5. If an object is dropped, the contestant must move to the next object (no object pushing to achieve goal zone)

2.12   Putting on or removing bolts from nuts with a nut driver (Level 3 - 30 points)

Items

1. 3.8 cm x 8.9 cm x 15.2 cm (1.5 in x 3.5 in x 6 in) length wood stud
2. Threaded inserts and installation kit
3. Hex Bolt
4. Nut Driver

Setup

1. Drill holes per Figure 4 and install threaded insert (this process could be a step in future competition)
2. Fix wood stud at predefined table location
3. Locate nut driver in locating hole on wood stud per Figure 4
4. Place mark on bolt threads 1/4 in (or 6 mm) from bottom surface of head
5. Start bolt thread and apply two full turns

Steps

1. The robot system grasps nut driver from predefined location in wood stud
2. The robot system uses the nut driver to drive bolt until fully seated

Rules and Scoring

1. Five points to engage nut driver with bolt
2. Ten points to drive bolt to mark or 25 points to drive bolt to full depth

2.13   Clip an artificial nail with nail clippers (Level 3 - 30 points)

Items

1. White, opaque acrylic
2. Vise
3. Permanent marker
4. Nail file

Setup

1. A piece of acrylic is cut (laser-cutting recommended) and clamped with an approximately 7.5 cm x 7.5 cm (or 3 in x 3 in) piece exposed (Figure 5)
2. A 1 cm long line is drawn (using the permanent marker) along the center of one of the edges of the acrylic piece
3. The acrylic piece is clamped using the vise such that the drawn line is exposed on the top

Steps

1. The robot system performs a grasp of nail file
2. The robot system uses the nail file to remove the edge so that the permanent marker is also removed

Rules and Scoring

1. 10 points for partial removal of the 1 cm line
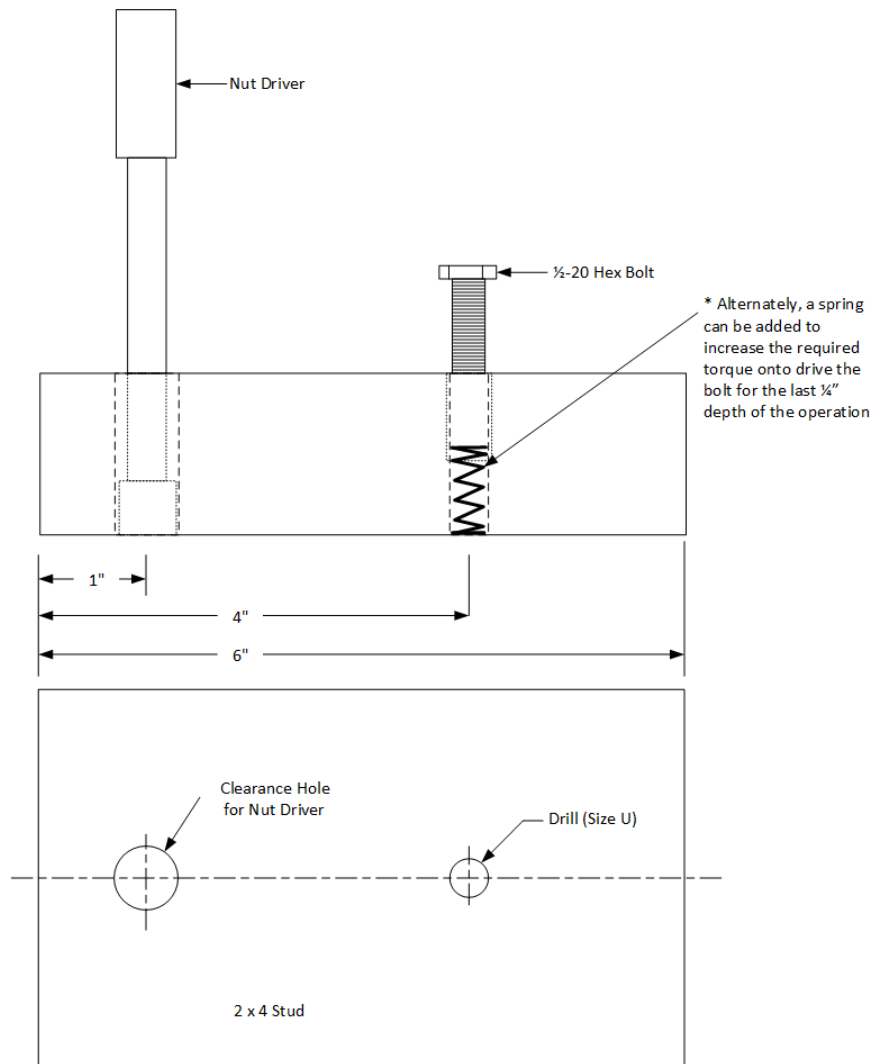2. 30 points for complete removal of the 1 cm line

Nut Driver

½-20 Hex Bolt

* Alternately, a spring can be added to increase the required torque onto drive the bolt for the last ¼" depth of the operation

1"

4"

6"

Clearance Hole for Nut Driver

Drill (Size U)
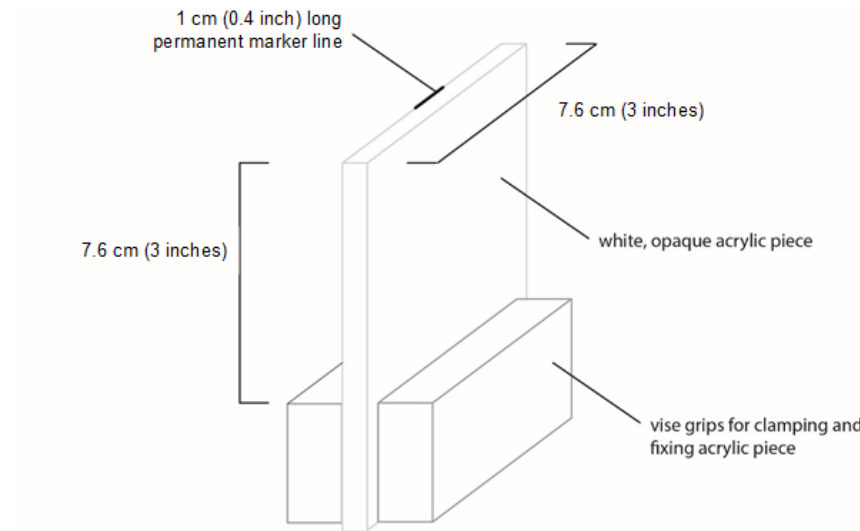
2 x 4 Stud

Fig. 4. Drive bolt setup

Fig. 5. File Nail setup

2.14   Use a saw to cut cardboard along a line (Level 3 - 30 points)

Items

1. Hand Saw
2. Clear plastic sign holders
3. Cardboard Inserts
4. Binder Clips

Setup

1. Align two sign holders with space between them to at least clear the saw kerf and fix to table top
2. Mark a 30.5 cm (12 in) cardboard filler insert with cut line at center and mark scoring at 1/3 intervals, 10.2 cm (4 in), along cut line (Figure 6)
3. Insert cardboard filler insert into sign holder with cut line centered and clamp using binder clips
4. Use left side of the sign holder to stage the saw for grasping

Steps

1. The robot system grasps the saw by the handle from staged location
2. The robot system uses the saw to cut the cardboard along cut line

Rules and Scoring

1. Ten points for cutting through each 1/3 section of cardboard along cut line for a total of 30 possible points
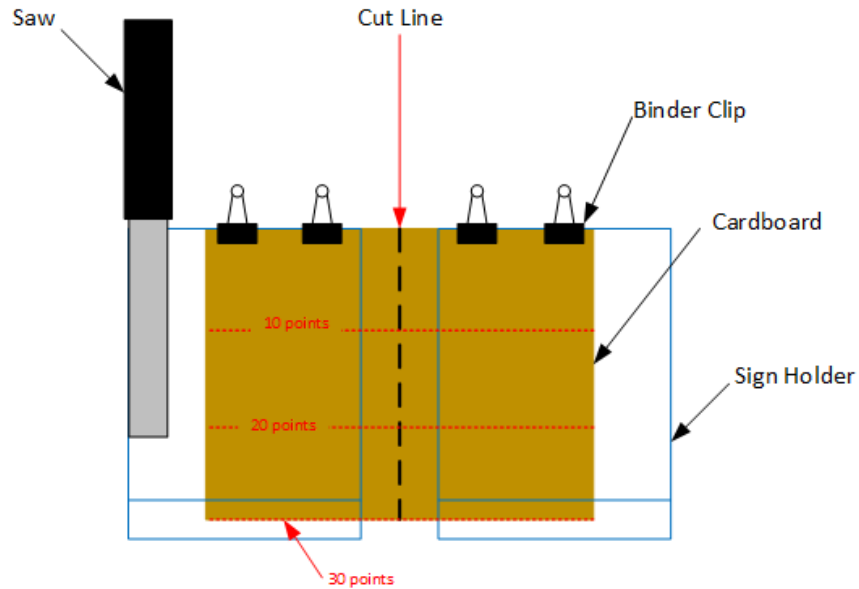
Fig. 6. Cut Cardboard setup

2.15   Fully extend syringe and then fully press syringe (Level 4 - 40 points)

Items

1. 30 cm^3 syringe

Setup

1. Set syringe in a fully compressed state
2. Place syringe on a flat surface

Steps

1. The robot system grasps the syringe
2. The robot system extends the syringe to at least 30 cm^3 (without removing the plunger)
3. The robot system returns the syringe to the fully compressed state

Rules and Scoring

1. 15 points to fully extend
2. 15 points to fully compress
3. The syringe base can be constrained by a means independent of the robot system

2.16   Open a bottle with a locking safety cap using Push Down and Turn Caps (Level 4 - 40 points)

Items

1. 3.8 cm x 8.9 cm x 15.2 cm (1.5 in x 3.5 in x 6 in) length wood stud
2. Pharmacy Vials 40 Dram (snap caps with safety push and turn cap)

Setup

1. Attach bottle securely to wood stud so that the attachment can withstand substantial twisting forces
2. Place cap on bottle and twist to lock
3. Fix wood stud at predetermined location on table

Steps

1. The robot system grasps the cap
2. The robot system applies a push and turn motion to the cap of the bottle to unlock it
3. The robot system removes the cap from the bottle

Rules and Scoring

1. Unlock cap for 20 points
2. Separate cap from the bottle 20 points

2.17   Peel a potato (Level 4 - 40 points)

Items

1. One large potato
2. One potato peeling device
3. 3.8 cm x 8.9 cm x 15.2 cm (1.5 in x 3.5 in x 6 in) wood board
4. Two, 10D 7.6 cm (3 in) Common Nails nails

Setup

1. Mark two nail locations centered on the board and 7.5 cm (3 in) apart
2. Hammer the two nails fully into the board so that the pointed ends of the nails protrude through the board
3. Clamp the board with nails points protruding upward
4. Push the potato onto the nails until the potato sits on the board

Steps

1. The robot system grasps the potato peeling device
2. The robot system uses the peeling device to remove the skin from the potato

Rules and Scoring

1. 10 points for each potato skin shaving
2. Up to 40 points total
3. Each shaving must be at least 2.5 cm (1 in) in length to achieve points

2.18 Use scissors to cut a piece of paper (Level 4 - 40 points)

Items

1. YCB Tool items: scissors
2. A4 papers

Setup

1. Prepare four pieces of A4 paper and draw each of the lines in Fig. 7 on each paper (straight line, polyline, curve and shape line). The shapes shown in Figure 7 should be drawn to fully utilize the A4 paper size
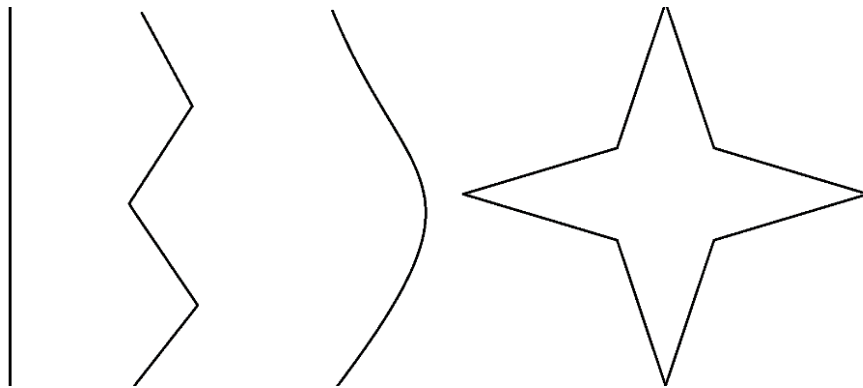2. Each line will define the paper surface into two parts

Fig. 7. Setup for cut pieces of paper

Steps

1. The robot system grasps the scissors
2. The robot system uses the scissors to cut a piece of paper into two along a straight line
3. The robot system uses the scissors to cut a piece of paper into two along a polyline
4. The robot system uses the scissors to cut a piece of paper into two along a curve
5. The robot system uses the scissors to cut a shape from a piece of paper

Rules and Scoring

1. Scoring is based on the accuracy of the cutting trace, where full points are awarded for all cuts that stay within 5 mm of the cutting trace.
2. Two points each for fully cutting straight line, polyline and curve
3. Four points for shape line cutting

3   Conclusions

Nine of the 17 tasks were released three months before the competition. Two weeks before the competition, 10 tasks were randomly selected from the 18 tasks and were released as the competition tasks. These included tasks 1, 2, 3, 4, 7, 8, 10, 12, 15, and 18. Four of the tasks where chosen from level 1, three from level 2, two from level 3 and one from level 4 for a total of 200 possible points. The chosen tasks are shown in Figure 8.

- Use a spoon to pick up peas
- Hang towel on rack
- Use a spoon to stir water in a cup
- Shake salt shaker
- Plug into a socket
- Hammer a nail
- Transfer straw into a to-go cup with lid
- Putting on or removing bolts from nuts with a
- Extend and press syringe
- Cut paper

Fig. 8. Listing of tasks chosen for the competition.

The tasks proved to be quite challenging to the teams that competed in the competition. Allowing teams access to a subset of the tasks throughout the competition registration process, preparation months prior to the competition, and practice days at IROS, led to a successful competition day where teams were prepared yet still challenged by final tasks presented. This pool of tasks will be used to support the next competition and the pool is expected to grow as new tasks are developed by the organizing committee.

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