METR 4202 -- Advanced Controls & Robotics
-- Lab 3: Systems & Controls --

Raise the BAR

Things are seldom what they seem;
Skim milk masquerades as cream.
-- Gilbert and Sullivan, HMS Pinafore

Welcome to the Robo Cup Café!

It's been said that few things sharpen sensing (and control) like a visit to the café. With this in mind, this laboratory turns its attention to assisting a barista make the cups in scenes of various levels of complexity.

Objective

Motivated by an always stimulating subject -- the delivery of coffee and tea -- this laboratory seeks to combine the principles of kinematics, dynamics, sensing, trajectory planning and motion control. We explore this through the coordinated manipulation of (potentially moving) cups so as to provide a customised, instant coffee/tea solution, via the design and operation of the Barista Assisting Robot (BAR).

Extending from Laboratory 2, the laboratory adds the process of placing drink satchels and condiments into the cups that were localised before. The robot may be designed using the Lego Mindstorm Kit (from Laboratory 1) or the UQ Robotics Dynamixel Servo kit. As a dynamic twist, the cups might be moving. This will be facilitated using a custom Brisbane Laser Turntable and a Pololu Mini Maestro 12-Channel USB Servo Controller.

Requirement

Design and build an automatic robotic system to either bringing the cups to a satchel "dispenser"or to bring the various items from this "dispenser" to the cup. Thus, given a set of randomly determined orders, the final system should complete the orders with the correct items in the correct cups as efficiently in both time and resources as possible. Importantly, given that the laboratory is about both quality and economy, the system should do this completely and strictly within seven (7) minutes (this allows teams upto two attempts per review).

In a similar manner to Laboratory 2, performance is based on a basic operation that may be extended. "Basic" operation is limited to three (3) robot actuators, where as "professional" operation may use up to four (4), but in so doing must operate at a higher standard.

Workspace and Operating Structure

The scene is similar Laboratory 2, but with the extension of a turntable and a robot arm. The working area is defined by a 40 cm × 40 cm square (approximately the areas of a Lego mat) and may by up to 30 cm tall. Teams may use a larger workspace if they so choose. As with the previous laboratory, there is a basic level of operation and advanced level of the workspace. This is outlined as follows:

Item	Basic Level	Standard Level	Professional Level
Number of Cups	$N = 1$	$1 \leq N \leq 2$	$2 \leq N \leq 5$
Clutter	No	Maybe	Yes
Max Number of Motors	3	3 (4 for challenge tasks)	4
Calibration Pattern	Allowed	Allowed	No
Mean turntable |speed|	$\omega = 0$ RPM	$\omega \geq 0$ RPM	$\omega > 2$ RPM
Item Dispensing	Coaster	Coaster	Coaster/Automatic
Performs Challenges	No	≥1	≥3
Espresso Requests	No	Optional	Optional
Urgency Requests	No	Optional	Allowed
Arm Operation	2D/3D	2D/3D	3D

Clutter is other extraneous objects to the scene including extra cups (which are extra the the N number of cups as indicated above), chocolates, marbles or wine glasses. Clutter may include filled cups with drink orders that were not completed by the robot. A Kinect, Kinect 2, and/or LifeCam camera may be placed in any location in advance of the operation of the system. Though, once the system starts the system has to be autonomous from that point forward. That is sensor-placement is a part of the system design consideration, but manual physical camera motion is disallowed (much as per Laboratory 2)

The Menu: Coffee, Tea, Sugar and More!

The items under consideration in this laboratory are as follows:

Item	Type	Picture
Coffee	Instant coffee satchel	
Tea	Tea Bag	
Sugar	White sugar satchel	

Cup fill specifications, or "orders," will be given based on the above "menu". The specification for this is: [order] = [N-drinks, [drink <1 to N>]].

where:

- N-drinks: Is the number of drinks (or cups) to be prepared (from 0 to N)
- drink is a tuple for each cup, given as:
  [drink] = [CupSize, Ncoffee, Ntea, Nsugar, Nespresso, IsUrgent], with:
  - CupSize: Medium [1] or Large [2]
  - Ncoffee: Number of coffee satchels needed [0, 2]
  - Ntea: Number of tea bags needed [0, 2]. Note that if Ncoffee is >0, then Ntea is 0. That is a drink will not ask for coffee and tea together.
  - Nsugar: Number of sugars needed [0, 3]
  - NEspresso [optional]: If the order is for a "fancy" espresso [0, 1]. Note: That Nespresso is 0 or 1 and if is 1, then Ntea and Ncoffee will be 0, that is a drink is either only a coffee, tea, or espresso. As "espresso" is an optional
  - IsUrgent [optional] = An indicator that the order is labeled "urgent" and that it is needed this first [0, 1]. If an order consists of multiple drinks with an IsUrgent of 1, it may fill these IsUrgent drinks in any order it chooses such that they are delivered before non-urgent drinks (IsUrgent=0).

Orders To Go: The Turntable

At the core of the laboratory is a moving (Brisbane Laser) turntable. Assembly Instructions and Video for the Brisbane Laser Turntable are on YouTube (thank you Mike Reed). It is driven by a Mini Maestro and requires drivers and external power (for the servo). Battery holders will be provided, but a 4-6V (500 mA) DC power supply should be sufficient.

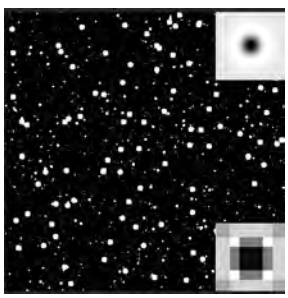
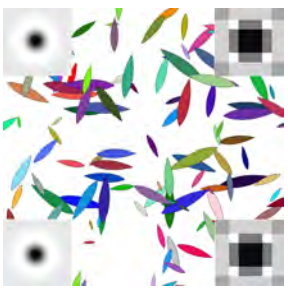
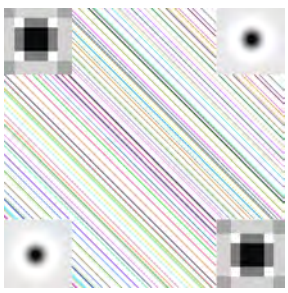
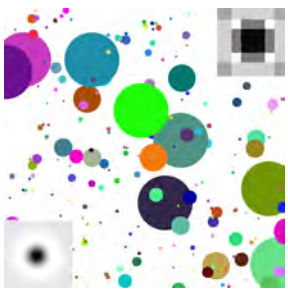
The turntable kit comes with a SpringRC SM-S4303R Continuous Rotation Servo [datasheet]. Its speed can controlled via the Maestro Control Center [cached download] or via serial commands (thus allowing for interfacing to MATLAB or C++). Teams are also allowed to place (print/write/tape) markings on the clear turntable so as to make it easier to see (this can include markings that fold down). Finally, teams are given a turntable kit and may assemble and place this in the workspace with their robot as they judge best.

The Dispenser: Retrieving Joy

The process of collecting items is handled by the dispenser. For the purposes of this laboratory, there are two mechanisms for dispensing the truth as it were:

1. (Tutor-controlled) Coaster Dispenser Mechanism -- In the standard configuration/operation there are 8 cm × 8 cm coasters with fiducials that distribute menu items. These include SIFT/SURF fiducials from Schweiger et al., "Maximum Detector Response Markers for SIFT and SURF", VMV 2009. For cups only, there is an automatic dispenser that will load a mix of coffee, tea, or sugar. The coasters will touch the main workspace, but may sit outside of it.

   In this case when the robot indicates (via a sound, text or voice prompt), a (tutor-driven, marionette-like) mechanism will provide the requested number of items over the area of the fiducial coaster. The dispenser has no robot/cup sensing. Thus, if the robot asks for two coffees, but places a manipulator (or cup) at the location for sugar, the "dispenser" will still drop the over the coffee coaster.

			
Coffee	Tea	Sugar	All Automatic Dispenser (cup only)

2. (Team-controlled) Automatic dispenser -- Teams are allowed to design and construct their own a dispensing mechanism (e.g., a preloaded item cradle) for the menu items. This has no tutor (or manual) intervention and is considered an optional "Professional Level" environment feature.

Eco-Friendly: Avoiding Spillage

No one like to have drinks spilled or ingredients wasted. Thus there is a small penalty for items that do not make it into the cup (i.e. those dropped along the way). There is also penalty for spilling the cup(s).

Server-Side: Indicating When Done & Serving Drinks

When the cups are filled (or when the system thinks cups are filled), the system should make announce this via an a clear, automatic mechanism of the team's choosing. This might be done, for example, via a chime sound, a prompt on the display or by tapping a glass.

If teams decide to manipulate the cups, they may professionally serve it by placing the cups on a coaster (of the team's design, up to 8 cm × 8 cm).

Go Pro: Beyond Basic Service

The Dynamixels are more capable and more challenging actuators. As they say, with such power comes great responsability. For "Professional Level" service or when attempting "Stretch Goals", there is an option to use the extra fourth motor/actuator of the UQ Robotics Dynamixel kit. This might allow for grasping and other related tasks. For those teams that perform "Professional Level" service with just three motors, such as those as part of the Lego NXT based kits, will be given +25% bonus points of extra credit.

To help teams rise from standard performance at a "Standard Level" to exceptional performance at "Professional Level" the laboratory introduces a number of independent "stretch goal" challenges. These include:

1. Place the cup on a coaster + ½ Point/Cup
   Serve the cup on a coaster of the team's design (as per "Server-Side")

2. Returning the cup to the rotating turntable + 1 Point/Cup
   Return the cup with requested drink items filled back to the moving turntable.

3. Sequence Control (aka "Hurry it up") + 1 Point + ½ Point/Urgent Cup Delivery
   An advanced robot should be able to prioritize and sequence operations. This allows for "Urgent Drink" service in which a drink may be given priority to be completed first. (n.b. this is a type of order and path planning problem known as "multi-goal planning")

4. "The Espresso Machine" + 1 Points
   The robot will accept orders for "Espresso". For OH&S reasons, we will use a 30 cm tall photocopier box on its side as a proxy for the machine. To make the espresso, a cup must be placed on a coffee coaster inside the box. As with the coasters, the "espresso machine" may partially extend past the operating environment. Device location may be set arbitrarily by the tutors before operation commencement.

5. "Supersize me" (aka "Roll your own") + 1 Point
   Replace the "Brisbane Laser Turntable" with a larger turntable (e.g., K-mart Storage Turntable) so as to move more cups simultaneously (>4). This means the system can also handle orders with a larger number of drinks. The team will have to engineer a connection from a continuous rotation servomotor to this turntable.

6. Pick up the condiments automatically + 2 Points
   Serve the cup on a coaster of the team's design (as per "Server-Side Push")

7. "Raise a Toast" + 1 ½ Points
   The robot will chime a wine glass to indicate that it is done and that drinks are ready to be served.

8. "Put a lid on it" + 2 Points/Cup
   The robot is able to take a lid (preferably to pickup one automatically) and place it over the cup. The robot does not need to secure the lid and may place the lid up-side-down.

9. Certified Open Source + 2 points
   An independent reviewer (e.g., Prof. Peter Sutton) is able to see that the development cycle is genuinely open source (e.g., with a full commit history, program structure, shared development, test codes, documentation, etc.). The entire code base in a release ready state including README (in text or MarkDown). INSTALL instructions are provided. All or nothing, no gimmicks!

Putting it on the Table: Laboratory Tasks & Values

The focus of the laboratory is advanced control and task planning along with integrated sensing and robot design. This involves coordinating the motion of the arm as well as the turntable.

The tasks for the lab include:

1. Drink Preparation + 4 Points/Drink

The system has to fill the menu items (coffee, tea, etc.) correctly for each drink.

2. Order Completion Notice + ½ Point

The system has to complete the order and correctly notify us that is it complete.

3. Timely Order Completion upto +4 Points

The robot fills the drinks in a timely manner (within 7 minutes maximum). If the entire order is filled within 5 minutes (½ point). If the order is completed <60 seconds/drink (1 point). If the order is completed <30 seconds/drink (2 points). If the order is completed <15 seconds/drink (4 points).

4. Spilling Cups -- 1 -- 2 Points/Cup

The system should not spill or knock over cups. If it does, it will be deducted 1 point for every empty cup that it spills and 2 points for every non-empty cup.

5. Dropping Menu Items -- ½ Points/Item

The system should not drop menu items (e.g., coffee, sugar satchels) outside of the cups.

The BAR-Exam: Overall Lab Mark

Grades will be determined by the teaching staff based on the performance, explanation and robustness of the solution. All team members are expected to understand and explain their system's performance on the aforementioned tasks.

In a nod to the Michelin Guide (though without the anonymous inspectors), these performance tiers include A general rule, but not absolute, mapping between points and grades is:

Grade	Points	Description
2 (20-45)	(0-2]	Instant Ramen -- Substandard performance. An order is attempted and at least one drink is filled with no more than one missing or superfluous item.
3 (45-50)	(2-5]	Plongeur -- A wash out performance. The robot operates only in a "Basic Level" environment only and eventually places order items in a stationary cup. Operations are inefficient. The drink, though, is correctly made.
4 (50-65)	(5-10]	Commis chef -- Basic level operation. At this standard level, the robot is operates well in a "Basic Level" environment and can operate some in a "Standard Level" environment. The drinks it fills are without error.
5 (65-75)	(10-15]	Sous chef -- Intermediate operation level [★]. This up and coming performance level handles a "Standard" environment with aplomb. Drinks are mostly filled accurately and spillage is limited. Performance is timely.
6 (75-85)	(15-20]	Head Chef -- Excellent/Advanced performance [★★]. A Professional standard robot. The orders are completed with superb accuracy in a "Professional level" environment. There is minimal spillage. The system attempts at least two challenge tasks and completes one.
7 (85-100+)	>20	Cordon Bleu Chef -- Exceptional performance [★★★]. This is robotics haute couture. A signature performance! Most of the tasks are attempted well with superb accuracy in a "Professional level" environment. There is minimal spillage. The system can defly perform at least two challenge tasks.
"8" (≫100)	≫	Roux Scholar Chef -- Elysian performance. Au-delà des mots. Not only are tasks handled in an inspired manner, but the solution exhibits incredible novelty and ingenuity. A best in class and country-leading performance. Rewarded with an exemption of the Individual Problem Set and more!

Teams and Groups

The project will be conducted in teams of up to five. You may also choose an individual from another group (or laboratory session) as long as you understand that you may not be able to work together for the final project that will draw upon work completed in this one.

Other Programming Systems and Cameras

Teams may elect to use programming languages and systems other than Matlab, such as Visual C or Python (i.e., the class is language / system neutral). In particular, teams may choose to use OpenCV. Teams may choose to operate the Kinect's RGB camera in high resolution mode (i.e., they may use the 1280x1024 mode also provided by the MS Kinect SDK as compared to the 640x480 default mode provided by the MATLAB interface). Similarly, teams may use another (web)camera on the proviso that the camera is autonomous (i.e., it can take pictures without manual intervention).

Calibration

In order to obtain a useful measurement, the Kinect needs to be calibrated first. Let us begin with the camera. As noted in class, the calibration parameters to connect raw images to 3D measurements are:

- focal length at the center (f_c)
- principal point offsets from the center (c_c)
- lens skew and distortion (α_c)
- Orientation (R_c) and Position (p_c) of the camera

There may be a misalignment of the x-axis of the image coordinate system and the base line. However, this can be ignored if the depth coordinate is defined parallel with the image coordinate system instead of the baseline, but this makes later coordination of sensor data to motion complex.

External Sites/Programs

Some external programs and site that might help with the process are:

- METR4202 Software Page (includes the Kinect for Windows SDK)
- CLAMS -- Calibrating, localizing, and mapping, simultaneously
- Robotis Dynamixel SDK for Windows & MATLAB

Due Date

The laboratory must be completed by Monday, November 3, 2014 or Wednesday, November 12, 2014. (This has been extended from the original date of October 31). Teams will be asked to submit a PAF after their demonstration. A short individual report (~1-2 pages) should by 11:59pm on November 15, 2014 via the Platypus submission system.

Early submission is encouraged..

Demonstration

As with Laboratory 1, the system will need to be demonstrated. During the demonstration period, teams may choose to demonstrate the focus area tasks in any order they choose; however, they have to serve "The First Customer" first. For each of the tasks, teams may repeat a task once if they choose; however, the team receives the value from either not both (i.e., repeat task demonstrations to not add).

Given the number of teams, the demonstration times are 20 minutes (maximum) total including setup and leaving 5 minutes for discussion. In this occasion, timing will be very strictly enforced. It is recommended that teams come at least 30 minutes in advance of their demonstration appointment. It is also recommended that teams practise their demonstrations in advance.

Judges

The course coordinator, lecturers and tutors will act as judges. The course coordinator will act as chief judge. All decisions made by the judges will be final, and no correspondence will be entered into. Contestants may approach the organiser about possible designs that may be questionable under the rules listed above. Any queries will be treated with the utmost confidentiality and will not be divulged.

Caveats

Some general "reasonable person" rules apply to the code and its execution:

- Codes with fixed (predetermined) position estimates are not valid (even if the value is correct).
- Internet access may or may not be present -- the code should assume that it will not have Internet access during execution and thus operate in a self-contained manner. A "Mechanical Turk" or "phone home" solution is explicitly disallowed.
- Memory space may or may not be cleared between challenges and submissions -- The memory space might be cleared before each function. Thus, if your routines rely on parameters to be exchanged, it should do so by writing to a file. Similarly, if certain variables names (e.g, counters) are used between functions, then be sure to initialize them correctly.
- All source code(s) may be assessed -- Thus, it is requested that it is commented. If custom precompiled codes are used (e.g., mex files), the source code should also be submitted.
- All submitted code should be able to run on a secondary machine
- Computational and memory resources -- the functions should be able to operate reasonably on a "standard" UQ EAIT Workstation (or equivalent). Judges may terminate execution after 2 minutes.

METR 4202: Robotics. Bon Vivant!