METR 4202 -- Robotics & Automation

Lab 3: Robotics Systems & Automation -- A Roboticists' Dilemma: Differential Games of a Domino Sort

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"Ah, but a man's reach should exceed his grasp,
Or what's a heaven for?"
– Robert Browning

Objective

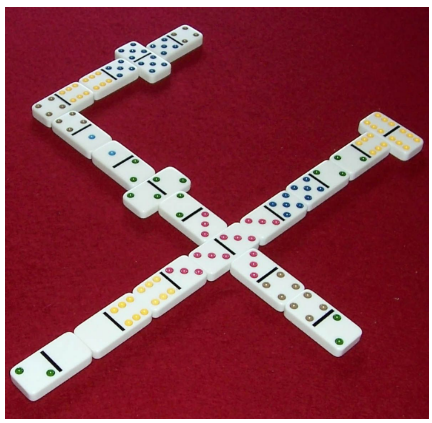
There is much in this uncertain world that seems in play. When confounded with such a cascade of choice and chance, what better to do then let a robot come to the rescue.

This laboratory explores the integration of principle elements of a modern robot: kinematics, sensing, motion planning, control, and intelligent decision making/game play as part of the process of an automated domino playing system in a potentially cluttered, unstructured and dynamic environment. While it may be a standard and common object, who said domines are childsplay?

The laboratory also adds a dynamic twist to Laboratory 1 and Laboratory 2, by allowing for dominoes to be on a (moving) plate. Together this allows for the consideration of dynamics in robotic systems integration and automation.

Gameplay and dynamics go together nicely: **it is a differential game**. While mathematically sophisticated, we need not limit our horizons; indeed, such parties are very much part of the fabric of daily life. As Isaacs notes, game theory is an essential element of **any** interaction, as pursuit and evasion are collateral: for evaders' maneuvers may deliberately confound pursuers' predictions.

With this in order, we shall explore a interesting case of automation of a domino sort!



Requirement

Design and build an automatic robotic system to manipulate dominoes. Depending on if teams are comfortable with AI/Decision Making/Game Theory, teams may choose between one of two distinct tasks:

1. **Playing Dominoes of a Sort**: The robot should be able to play a basic "Draw Game" for two players (itself and one opponent). Seven (7) dominoes are drawn randomly before the game starts. Similar to the "Muggins" variant, the line of play may be extended in either direction. It is equally acceptable for tiles to be face-up or standing depending entirely on the robot's (team's) choice. Additional details of the METR4202 variant are below.

2. **Sorting Dominoes of a Play**: In this distinct task variation the robot should be able to sort a set of standard dominoes after a game play. The dominoes may (or may not be) randomly arranged. All dominoes will be be face-up.

The plate/turntable serves as a domino "boneyard" -- for what goes around comes around. Tiles may be face-up or standing again depending entirely on the team's choice. The first tile is selected randomly by the judge from the "boneyard."

Importantly, given that the laboratory is about dynamic play, the system should do this completely and strictly within ten (**10**) minutes.

Scene Structure

The scene is similar to Laboratory 2, with operation in a Basic Level environment showing a standard understanding of the core concepts, whereas a operation in a Skillful Level environment showing that the system adeptly and automatically exploits dynamic structure. The workspace will be defined with varying levels of structure and clutter, with lower performance standards having more structure. This is outlined as follows:

Item	Basic Level	Skillful Level
Background	Monocolor non-white paper (teams may remove it)	Anything (**including clear**) (encoder rings/paper okay)
Clutter	No	Yes
Number of dominoes	Turntable: $0 \leq \mathbf{N} \leq 7$ Sort: **N**: 15 (**double-4** set)	Turntable: $7 \leq \mathbf{N} \leq 14$ Sort: **N:** 28 (**double-6** set)
Lighting variations	Room	Room + Flash/Spotlight(s)
Mean turntable |speed|	$\omega \geq 0$ RPM	$\omega > 2$ RPM
Suggested Workspace	Similar to Laboratory 1	Lego Baseplate (~0.2 m^2)

Robot and Turntable Kits

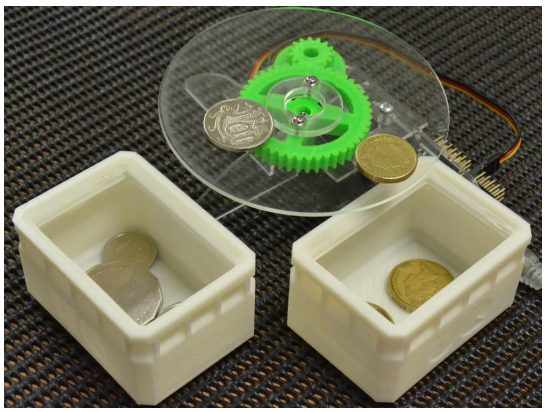
At the core of the laboratory is the robot. The robot arm structure may be built using provided Lego NXT kit (similar to Laboratory 1) or a Dynamixel-based UQ METR Dynamixel Kit. These may be selected equally by the teams based on their preference. There is no advantage for using one kit over the other. In both cases the system must operate with the robot actuators provided the respective kits (including the turntable's servo).

In addition to the compliance of the Lego/Dynamixel structure, it is advised that teams consider using a compliant end effector. Some of the various mechanisms for this include: a small paint brush, an eraser, a pendulum mass (e.g., like a crane -- the string is a very compliant mechanism), plastic fork, compressed air, vacuums, etc.). Teams are also allowed to place (print/write/tape) markings on the turntable so as to make it easier to see (this can include markings that fold down).

Optionally, the laboratory also allows a potentially moving turntable such as that based on a custom Brisbane Laser Turntable design driven by a Pololu Mini Maestro 12-Channel USB Servo Controller. **Assembly Instructions and Video for the Turntable** are on YouTube (by 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++).

Should a domino flip face-down while coming of the turntable, teams may manually flip it face-up, without moving the position/pose of the domino to an extent reasonably possible.



Roll Your Own Turntable (Optional)

Should teams wish to, they may optionally decide to make their own turntable or domino boneyard motion providing device by modifying the aforementioned Brisbane Laser Turntable or from scratch. There is no extra credit or direct advantage for having one's own or using the kit turntable.

Basic Domino Game Rules (METR4202 Variant)

This lab adopts a variation of the basic two-player Draw Game rules for a double-six set in which the turntable acts as the "boneyard" for spare dominos and where the robot may play face-up.

Summary of METR4202 Variations:
Some variations for simplicity of robot play are: (1) the turntable and/or the area near it act as the boneyard and (2) if the robot chooses, the boneyard may have the dominoes face up, (3) the robot plays first (or has the first right of refusal), (4) the first double domino is the one and only "spinner", and (5) "blanks" can be used as "wild cards."

Setup:
After shuffling dominoes, the judge will give 7 dominoes to the human player (**H**) and the robot (**R**). The robot may request the dominoes face-up, standing portrait or standing landscape (the latter two options prevent the opponent from seeing the robot's hand). Extra dominoes are placed on the turntable "boneyard" or the area near it (should the turntable overflow or not be used).

Turntable "Boneyard":
The turntable serves as the cache of extra dominoes. The team may choose if the boneyard dominoes are face-up, standing, or face-down (all equally fine). The number and speed of dominoes depends on the scene and level of difficulty.

Gameplay:
The robot starts first (unless it is a robot/robot game, in which case this is decided by coin toss), but has the right of first refusal. Dominoes may be added to any open end of the layout. The layout may flow in any direction, turning as necessary.

▸ Double Dominoes and "Spinners":
A double domino should be placed in a crossways orientation. The first double domino (regardless of when played) becomes the "spinner" (because the domino chain grows from all four sides).
▸ Blank Dominoes:
Blanks can be used as "wild cards" and may join tiles regardless of numeral including other blanks.
▸ Drawing and Passing:
If a player is unable to make a move, they must draw dominoes from the boneyard until they can make a move. If there are no dominoes left, then the player must pass.

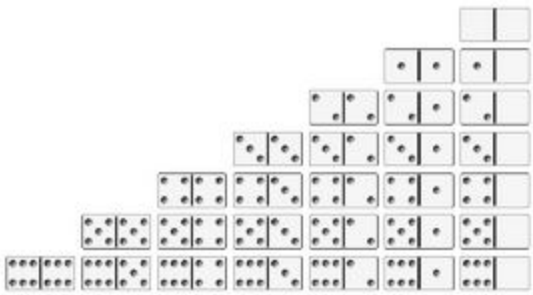
Game Completion (End Condition):
A game ends either when a player plays all tiles, or when a game is blocked. A game is blocked when no player is able to add another tile to the layout, in which case the "winner" is the one with the lightest hand (i.e. the fewest number of dots on their dominoes).

Scoring:
The match score is the total points (pips) in the opponent's hand minus the points in their own hand (if any). A METR4202 robot game consists of upto three matches. The total score is six times **(6×)** the **median** score of the matches. (Note: there are 168 total pips in a double-six domino set).

Valid Plays Only Please:
For each turn, the player should try to match pips and should reasonably match intended position and orientation (as determined by the judge, but within 2.5 cm). If either player makes an invalid move the judge may remove the domino and add it to the boneyard. After **three (3)** invalid attempts, the game is forfeit as incomplete.

Domino Sorting Rules

An alternative task for teams that do not wish to construct a game-playing system (as not all teams may have taken the AI course) is to sort dominoes. The goal of the task is to return the dominoes in a standard order/pattern as advised by the robot in advance. A recommended pattern is the standard double-six Domino Triangle as shown below. Another alternative is by total pip value.



Standard Double-Six Domino Set (28) Triangle
[Source: Baylor | Note: Domino Type is also part of Unicode]

The number of dominoes on the turntable is determined by a dice throw (one dice for Basic level and two dice Skillful level scenes). Remaining dominoes are let in situ from either a previous game or random toss/placement.

Basic Level Simplification:
The sort task is for a reduced "double-4" set consisting of the 15 dominoes with four or less pips (i.e., the first five rows of the figure above)

Objective and "Par Scoring":
The task is to deliver the the dominoes properly sorted to a pattern preannounced by the team/robot (i.e., the robot may inspect the scene and then declare how it will sort the dominoes). The standard double-six Domino Triangle (shown above) is assumed as default if an alternative sort is not declared. **Scores are derived "from par" of 100**, such that total number of pips (points) for every misplaced or missing domino is subtracted from 100.

Other Robotic Systems, Languages and Cameras

Teams may elect to use programming languages other than Matlab, such as C++ or Python (i.e., the class is language/system neutral). In particular, teams may choose to use OpenCV. Teams have available for use one of either the Kinect 1, Kinect 2 or a standard WebCam. If using the Kinect 1 or Kinect 2 teams may use both the RGB and D cameras. When using the Kinect 1, teams may choose to operate the 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 Libfreenect). Similarly, teams may use another (web) camera on the proviso that the camera is autonomous (i.e., it operates **without manual intervention** including file copying).

Teams and Groups

The project will be conducted in **teams of up to six.** The is presumably, but not necessarily, your group from Laboratories 1 and 2. That is, you are welcome to reform teams. If there are team dynamic issues, you are encouraged to do so and the teaching staff is happy to arbitrate (i.e., reassign team members). Please notify the teaching staff of changes by October 24, 2016.

Pointers*: Assessment Criteria for Overall Lab Mark

Grades are not just about points (or pips). Let us consider a process to be spot on about grades:

Teams are expected to do either the Basic Game **xor** the Sorting "core task." While it is encouraged for teams to have domino motion, they not have a moving turntable. Grades will be determined by the teaching staff based on the performance and explanation of team members as they perform the aforementioned area tasks. A general, but not absolute, rule the mapping between points (or value) and the grades is:

In short for the following grade levels:

- 1-3: Teams attempt and are somewhat successful at a "core task". Performance is mediocre.
- 4: Teams attempt some and are marginally successful completing a "core task". The scene has to be highly structured and/or teams require more attempts than are feasible in a typical assessment time window.
- 5: Teams attempt a "core task" and are able to complete it in Basic Environment.

- 6: Teams attempt the "core task" in a Skillful Environment and are robustly successful this including the presence of noise/clutter/etc. There is domino motion. In game play, the solution is able to produce a result capable of winning occasionally (a weak player). In sorting, the system handles 5-pip series dominoes robustly and 6-pip series domino well such that it receives a "75" or higher score.
- 7: Teams robustly and successfully complete a "core task" in a Skillful Environment with deft skill and aptitude. Rising above the "Grade 6" standard, teams show an algorithmically strong player (i.e., a solution that should win games most of the time). In sorting, the system handles all dominoes robustly such that it receives an "85" or higher score.

As a rough guide that mapping between tiles and the grades is:

Grade	Indicative Score	Description
2 (20-45)	N/A	At least one task performed. For example, you are able to get all the systems to turn on and for the robot to touch to turntable.
3 (45-50)	N/A	Very substandard performance, For example, you are able to detect the dominoes and move the arm.
4 (50-65)	N/A	**Basic level operation.** For example, you are able to detect and move at least four dominoes.
5 (65-75)	N/A	**Intermediate operation level.** For example, you are able to sort most of the double-4 set | Play a little.
6 (75-85)	~ 75	**Very good intermediate to Advanced Level performance.** For example, dominoes are sort skillfully | played well in an advanced level environment.
7 (85-100+)	~85	**Excellent performance**. The task is attempted very well. Teams are able to robustly move objects in complex scenes with superb accuracy in an advanced level environment.

Due Date [Demo: Oct 27-Nov 21]

Due to supplier issues with the Turntable servo, the lab has been **extended** so that it should completed and demonstrated at a laboratory time of the team's choosing between **Thursday, October 27, 2016 and Monday, November 21, 2016** (*selected online*). A short, brief **individual** and **group** report (~1 page, details in class) should also be submitted. It is due by 11:59 pm on **November 17, 2016** via the Platypus submission system. Early submission is encouraged.

An "open tournament" demonstration day on **November 21, 2016** for prizes (including the coveted "Le Grande Domino") and extra credit up to (15/100 or 12% of the overall grade).

Demonstration

As with the previous laboratories, the system will need to be demonstrated. Sign up will open on October 24. During the demonstration period, teams may choose to demonstrate operation in **any order** they choose. Teams are allowed to repeat operation up to three times (i.e., three matches or sorts). In both cases, the final score is the **median** performance.

Given the number of teams, the demonstration times (of 30 minutes total including setup and discussion) will be strictly enforced. It is recommended that teams come 30-45 minutes in advance of their demonstration appointment. It is also recommended that teams practise their demonstrations as time limits will be enforced even if teams have not been able to demonstrate their solutions to the tasks (i.e., teams will receive grades on the solutions they demonstrate not the solutions they might have, but did not deliver). Teams should try to be finished in 15-20 minutes if possible to leave sufficient time for discussion.

Extra Credit

As custom level and extras credit ideas are sent in and approved, they will be posted here for the benefit of other teams. Some approved custom advanced level and extra credit ideas are:

- Integral use of turntable -- 15/100 of extra credit
  (with "integral" determined by judge, but including multiple accesses and necessary selection of dominoes as needed. Specifically excludes ad hoc attempts, those that clear all/most dominoes, arbitrary domino motion without system consideration).
- Demonstration before exams (before November 5) -- 15/100 of extra credit
- "Open Tournament" Day -- **Up to** 15/100 of extra credit
  (e.g., enter and reasonably compete: +5, semi-finals: +10, finals: +15)
- Post the operation of the robot to YouTube -- Teams that post videos of the solutions on YouTube will get from 1-5 points depending on the quality and clarity (as determined by the teaching team and the award-winning, independent UQ Robotics film critic, Ellenor).
- Fastest Team -- The tutors will measure the time it takes the teams to complete the various tasks. The fastest team(s) for each task will get a reward (depending on its speed).
- Spinmeister -- The team with the fastest (mean) speed table that is able to partially sort.
- Open Source Code -- The entire code base is properly documented and shared on a public, open-source repository (e.g., GitHub)

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 confidentiality and will not be divulged.

Individual Grade

Each member's individual grade will be computed from: The average assessment of the team by the teaching staff at the demonstration, The peer assessment factor, and the report.

The final score is then computed as follows: Individual Normalized Grade =
([PAF]*[Lab Demonstration (out of 100)] + Group Lab Report (out of 15) + Individual Lab Report (out of 10)) * ...
([Total Score to Normalize to a Percentage (in this case 1/125)])

[PAF] = (([Number of Team Members] * [Individual PAF]) / ([Sum of PAFs for the Group])) ^ 0.60

Hints and Comments

- It might help to have a compliant end effector (e.g., brush), but the arm can be rigid.
- You are allowed to put down a tablecloth / table paper (colored paper) of your own choosing and design (it can include a checkerboard pattern). You are allowed to insert your own targets (e.g., colour targets) and frames.
- If teams which to go **backwards**, please remember to **tape** (not screw) down the small servo drive gear or the turntable will come apart! (remember that speed does not include direction, it is the absolute value of the magnitude of the velocity vector)
- Teams are allowed to make an encoder ring (from paper) this does not count against the "transparent rule" as long as its area is less than 50% of the turntable's area (not radius).
- Semi-transparent paper (e.g., wax paper) is considered transparent if one can "see" a domino inserted under the turntable.
- A pendulum mass (e.g., crane) is also an option (though this makes more sense in conjunction with input shaping (anti-sway control)).
- Unlike a hard drive the mechanism is not designed for stepper operation -- though if teams wish to operate the platter like a hard drive, they may "PWM the drive" as long as the mean speed is within the given speed threshold and that the duty cycle is >25%
- Yes it is still a controls problem, a hard drive would be impossible without control.

References

References:

1. Domino Muggins game pictures (on red background) is cropped from WikiMedia (Liko81) https://en.wikipedia.org/wiki/Muggins#/media/File:Muggins.jpg
2. Domino Rules derived from instructions at: http://www.domino-games.com/domino-rules/

Standing on the Shoulder of Giants

Domino recognition and robotics has been explored in the domain. You are encouraged to adopt a principled approach and use cited-citations. Please be sure to reference appropriately.

- Stanford Domino Playing Robot (DomiBot): News Article | Video | Github repository

Caveats

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

- It is a deep thought, indeed a noble one, but what is obvious might not be optimal.
- It is expected that teams will use source/version control.
- Codes with fixed (predetermined) 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. This proviso excludes UQ license servers that may be needed by the program (e.g., Matlab). 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.
- Each team's submitted functions will be run in their own directory -- Reading other teams' files or memory is disallowed.
- 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 and compilation instructions (e.g., makefiles) should also be submitted.
- Computational and memory resources -- the functions should be able to operate reasonably on a "standard" Laptop/Workstation class computer (such as the UQ EAIT PC Workstations). Judges may terminate execution after 5 minutes.

Summary of Revisions

Due to some unexpected turntable servo supplier issues beyond our control, the due dates and specification have been revised (extended) such that no part of this is due/assessed during swot-vac (contrary to popular myth, UQ assessment policy does not preclude due dates during swot-vac or examination periods). In particular, revisions include:

- Final Submission **Extension** to a time of the team's choosing from October 27 upto November 21.
- Turntable use is optional (extra credit if used in an integral manner)
- Tournament (and it's associated extra credit) is open only to domino playing robots.

METR 4202: Spot On Robotics!