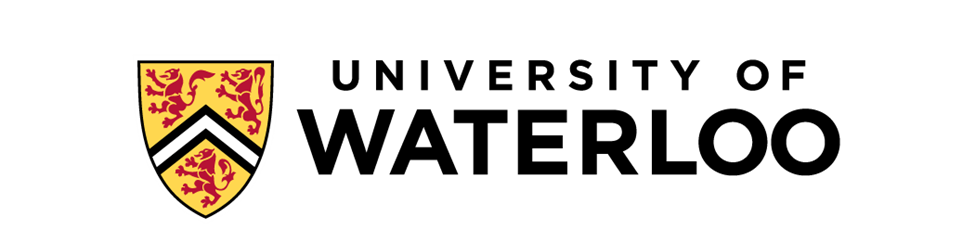
**Group 4 - 20**

**Waterloo** Engineering Expeller **of Dominoes**

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**Department of Mechanical and Mechatronics Engineering**

**MTE 100 / MTE 121**

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-domino people

**Summary**

The task of setting up dominoes to be knocked down in a chain reaction is tedious and time consuming. To solve this issue the Waterloo Engineering Expeller of Dominoes was created. This robot was able to set up 30 dominoes in a line while following a list of instructions from a file or by following a line drawn on the ground.

The project was broken into smaller tasks for each group member such as building individual mechanical subsystems or programming functions. A schedule was also created and revised to ensure a timely completion of the project.

To build this robot, lego pieces were used to construct a physical assembly which integrated sensors and motors from the EV3 kit. The robot was designed to move dominoes from a storage hopper down a release chute through the use of an actuated dispenser arm. These dominoes would then fall to land in a standing position. A rear door would then open, leaving the domino standing on its own. These subsystems were integrated together and programmed using RobotC to leave a free standing line of dominoes behind the robot.

A digital path was created using a Python program, which integrated the pygame library to create instructions for the robot to follow. The goal of the robot was to set up dominoes in a line while following a digital path or drawn line while responding to external factors. Some of these factors included objects placed in front of the robot, which prompted the robot to pause operation until the obstacle was removed, or user inputs to the touch sensor which activated the shutdown procedure. This shutdown procedure would end the setting up of dominoes either once the robot ran out of dominoes or the touch sensor was pressed.

The goal of setting up 30 dominoes in a timely manner was met, as the robot could set up all dominoes in under five minutes. The robot was also able to successfully follow the digital path or drawn line. In the end, the Waterloo Engineering Expeller of Dominoes was designed and built within the scheduled time and was able to set up dominoes reliably through a strong mechanical design and effective programming. The specifics of the mechanical and software design of the Waterloo Engineering Expeller of Dominoes, as well as ideas for future improvements are outlined below.

# 1.0 **Introdu**ction

Creating a standing line of dominoes is done for the purpose of knocking them all down in a large chain reaction. However, this goal can be tedious or inaccessible to some. The coordination and spacing required to set up dominoes can sometimes be demanding causing the entire chain to fall. This coordination and repetition of tasks is exactly what a robot can be used to complete. The Waterloo Engineering Expeller of Dominoes was created to solve this exact problem. Automating the process of placing dominoes to create a robot that not only sets the dominoes up in a straight and consistent fashion, but also places them along a simple to create, predetermined path.

**2.0 Scope**

**2.1 Main Functionality**

The robot completed the task of setting up dominoes automatically in a path that can be knocked over in one chain reaction. The path that it laid the dominoes on was determined either by a line that was drawn on the ground that the robot followed through colour sensors, or by a path that was drawn digitally and sent to a file which the robot read. It then proceeds along the path, cyclically dispensing dominoes out behind it. Functionality was added to automatically pause all operations if an obstacle was placed in front of it while simultaneously alerting the user with a sound. It would then proceed once the obstacle was removed. Finally, the robot was programmed to have the option to knock down the domino chain on its own, or wait for the user to knock them down theirself.

**2.2 Inputs**

The robot had a number of inputs that it used in its regular operation. Firstly, it took information from the buttons on the EV3 Brick in order to select an operating mode. In file follow mode, it would receive a file of instructions (previously a list of coordinates) that was generated beforehand and drive the appropriate path. In line follow mode, the robot would detect a coloured line below it and follow this line, placing dominoes. Initially this was planned to be done with a single colour sensor and gyro, however a method using two colour sensors was more favourable. It would use information received from two colour sensors placed on the bottom of the robot to follow a line drawn on the ground. Regardless of the mode, it would continuously read the inputs from the ultrasonic sensor to detect obstacles or read from the touch sensor to start the shutdown procedure. This was changed from the initial idea of the touch sensor functioning as an emergency stop button.

**2**.3 Interaction with the Environment

The robot had four motors that allowed it to interact with its environment. Firstly, two large motors were connected to the wheels, driving the chassis. These allowed the robot to move across the ground in two dimensions and thereby complete its designated path. There was also one medium motor connected to a dispensing arm that pushed dominoes from the domino hopper down a ramp and into its final position. Lastly, another medium motor operated the door, allowing the dominoes to be released out the back of the robot. The colour sensors on the robot were used to follow the line by detecting the white space on either side of the drawn line. If either sensor did detect the line below, it would change the robot’s path accordingly to stay directly on top of the line. As mentioned previously the ultrasonic sensor would sense for obstacles in the way and alert the user to remove it. The rest of the previous inputs described were all human controlled.

**2.4** Shutdown Procedure

The general operation of the robot consisted of one of two main operational loops depending on which mode was selected. One way to exit these loops was for the robot to run out of dominoes; there was an internal count stored as an integer variable that would decrement each time a domino was released, and the robot would enter its shutdown procedure once this value reached zero. Alternatively, the loop would be exited if the touch sensor was triggered, at which point the robot would automatically topple the last domino placed and shutdown.

To begin the shutdown procedure, the robot would first stop all operations, that is, all motors would be turned off and all loops would be exited. The robot would then wait for the touch sensor to be pressed which would cause it to topple the first domino starting a chain reaction. If the touch sensor was not pressed within ten seconds of the start of the end procedure, the robot would exit the program without toppling the dominoes.

**2.5 Changes to the Scope**

The largest change that was made to the scope of the project since the beginning was the decision to use two colour sensors to follow the line instead of one. While the initial intention was to use just one colour sensor working in tandem with a gyro sensor, it was decided that it would be very difficult if not impossible to create a reliable path-following program with this combination of sensors. The plan was then altered accordingly to use two colour sensors, making it more realistic and achievable.

Furthermore, a small alteration was also made to the functionality of the touch sensor. As mentioned above, the touch sensor was originally going to serve the purpose of an emergency stop button. It was decided that it would be more useful if it also made the robot topple the first domino, as it added extra functionality and was simple to implement.

**3.0 Constraints and Criteria**

**3.1 Constraints**

The robot had two main constraints: the amount of dominoes it could carry and the time it took to place them. The robot could carry up to 30 dominoes and had to place them in less than 5 minutes, since that was the maximum demonstration time. Both constraints were valuable in creating a realistic, achievable goal.

Over the course of the project, those constraints were changed. Initially the maximum number of dominoes to be carried was 60, because that was the available resources. However, it proved very difficult to carry that many dominoes because of the weight it created on top of the other dominoes, which increased friction. Secondly, the initial target-time planned for was ten minutes, however this was later cut to five due to demonstration time constraints.

**3.2 Criteria**

The robot was expected to place the dominoes correctly and evenly spaced from each other, and have them fall in a chain reaction when one was knocked over. It was also expected to follow a line or a path from a file uploaded to it while simultaneously setting the dominoes. The criteria were not changed during the development of the project. Both criteria were helpful in designing a functioning robot as they were crucial in guiding both the software and hardware design processes.

**4.0 Mechanical** Design and Implementation

The Waterloo Engineering Expeller of Dominoes was designed to efficiently set up dominoes along a created path which could then be toppled in a chain reaction. This was done by moving a domino from a storage hopper to the release chute through the use of an actuated arm. Once the domino fell down the release chute and landed standing up, the robot opened the release door and drove forward to leave the domino standing. The robot also utilised colour sensors to follow a line drawn on the ground or gyro sensors which allowed it to follow premade instructions. The robot also had functionality to react to external factors such as objects in its path or an input from the user through the touch sensor to knock over the chain of dominos.

## 4.10 Chassis design

The chassis of the robot was designed with a focus on structural stability, connecting to all essential parts. These parts included the ultrasonic, colour, touch, and gyro sensors along with, the hopper, door assembly, drive motors, dispenser arm, release chute, and the Brick. The overall shape resulted in a drivetrain base with a sturdy frame extending to the front securing the dispenser arm as seen in *Figure 1: Main Chassis.*

A picture containing indoor

Description automatically generated

Figure 1: Main Chassis

### 4.11 Hopper

The hopper assembly was designed to allow for gravity to feed domino's down towards the dispenser arm. The original design consisted of three columns which held dominoes perpendicular to the release chute. The dominoes were to be dispensed and rotated 90 degrees as they fell into the correct orientation. After much testing, this design was determined to be too unreliable and was changed to a hopper with two columns in line with the release chute. This design held fewer dominoes but the path the dominoes took to the release chute was much more reliable. As seen in *Figure 2: Hopper Section View with Arm,* both columns of dominoes would fall to be in line with the dispenser arm, with the rest of the stored dominoes being stacked on top. As the dispenser arm contacted the first domino, it would connect with the second domino, pushing both dominoes. As the arm pushed the dominoes, it would slide under the stacked dominoes holding them up. Once both of the dominoes were dispensed, the arm would slide back from under the stacks of dominoes causing them to fall into place. This cycle could continue indefinitely until the robot ran out of dominoes.

A picture containing indoor, toy

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Figure 2: Hopper Section View with Arm

### 4.12 Release Chute

The release chute was positioned at the back of the robot to funnel dominoes from the hopper to the release door. The chute was originally designed to orient dominoes the correct way before they fell into the release chamber. This proved to be difficult to do with Lego parts as the domino would need to rotate 90 degrees on two axes from the hopper to the release chamber. The final release chute was designed to be a simple ramp to guide a horizontal domino to a vertical one as seen in *Figure 3: Chute Side View.*

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Figure 3: Chute Side View

## 4.2 Motor Drive Design

### 4.21 Drivetrain

The drivetrain assembly was constructed in a relatively simple fashion with a large motor powering the left wheel and a large motor powering the right wheel. A steel ball caster added a third point of contact with the ground which improved stability. Originally the motors drove the robot from the front, but this caused the back portion of the robot to swing out around turns. This was a critical flaw as dominoes were dispensed from the back and had to be positioned precisely on the line. The chassis was adjusted to have the driving motors be at the back, in line with where dominoes were dispensed. The position of the steel ball caster was also moved to the front. Consequently, the large motors had to be mounted and programmed backwards so they would fit the form of the chassis. The overall chassis as seen in [view of chassis] was now driven from the back to allow for the dominoes to be accurately placed on the line.

### 4.22 Pusher Arm

The dispenser arm was originally designed to resemble a piston and crankshaft with a rotating arm that actuated the dispenser arm in and out. This motion pushed a domino out then retracted to allow another to fall from the hopper. This design was later changed as the ratio of rotational to linear motion deviated too much. The newer design, as seen in [figure of arm], was composed of a rotating arm, a horizontal moving pusher and a linkage bar. The lengths of the rotating arm and linkage arm were tested and rebuilt to find a combination that optimised the linear motion of the horizontal arm. The ratio of rotation of the rotating arm to the horizontal distance the pusher arm slid was then also more consistent. This design was slightly modified one more time as it was observed the rotating arm initially pushed down vertically on the assembly rather than horizontally. The length of the linkage and rotating arms were once again modified resulting in the most effective pushing arm.

### 4.23 Door

The rear door of the robot was designed so that the dominoes were stabilised before being released. The dominoes fell into a chamber between the chassis and the door, then the door opened and the whole robot drove forward leaving the domino standing. The robot then closed the door and repeated this process. The original door design consisted of a rack and pinion gear which rotated to bring the door upward. After several attempts at designing such a mechanism, it was found the gears would sometimes slip and the construction of the frame was overly complex. It was decided that a rotating door as seen in [figure of back door] was much more simple and reliable.

## 4.3 Sensor Attachment Design

### 4.31 Color Sensors

A system of two colour sensors were used to accurately and consistently follow a black line. Both sensors were positioned to be in line with the axles of the drive wheels. This was because the robot had to follow the line, while still keeping the domino release area on the line. The sensors were mounted facing downward as seen in [Image below] with the spacing between them being around the thickness of the drawn line.

### 4.32 Ultrasonic Sensor

The ultrasonic sensor was mounted on the front of the robot, facing forward, as seen in [Image below]. This allowed the robot to detect any objects and alert the user if there was something in the way of its path. This was done by stopping the robot, playing a sound, and displaying a message to the screen, until the object was removed.

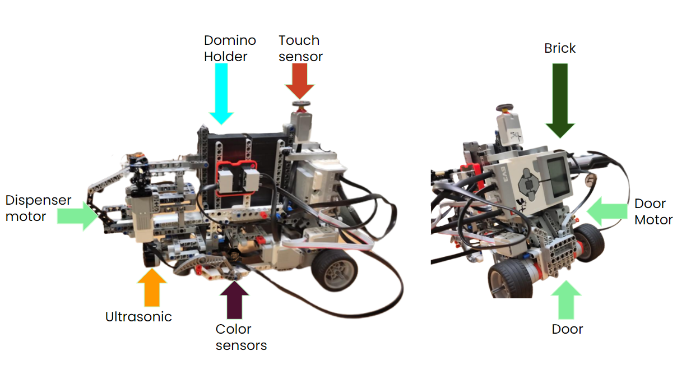
### 4.33 Touch Sensor

The touch sensor was positioned on top of the robot to be accessible by the user, as seen in [Image below]. When pressed, it would stop the robot and drive it in the reverse direction for a short distance to start the chain reaction and knock down the dominoes as described in the shutdown procedure. [cross reference]

### 4.34 Gyro Sensor

The gyro sensor was originally mounted on one side of the robot opposite to the placement of the medium door motor. However, this caused the robot to leave inconsistent spacings between dominoes when turning, as the sensor would change angles at different ratios depending on turn direction. To solve this, the gyro sensor was remounted on top of the Brick, centred on the robot, as seen in[Image below]. This resulted in a more accurate reading. The gyro sensor was used to regulate the rate of rotation of the robot.

## 4.4 Overall Assembly

The robot systems were designed to work in unison to successfully dispense dominos. The drive wheels were mounted to be in line with the domino dispensing chamber to allow for accurate placement on the line. The colour sensors were also attached close to the drive wheel and release chute so this section of the robot would remain over the drawn line. The hopper and dispensing arm were mounted close to the front and center of the robot which pushed dominos to the back dispensing area. Each sensor was mounted in their respective locations as mentioned in sections 4.31, 4.32, 4.33, and 4.34. The EV3 Brick was also mounted above the dispensing area above the drive wheels to help with traction and allowed easy access to the display and buttons****Figure 4: Full Robot Sideview

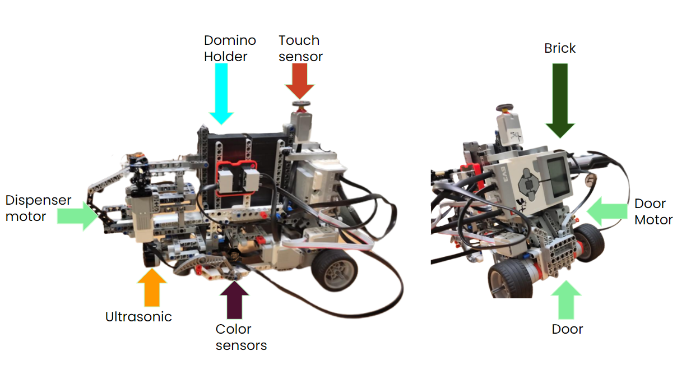


Figure 5: Full Robot Back View

**5.0 Software Design and Implementation**

## 5.1 Overall Software Design

### 5.11 Sub-division of tasks

The main code’s function was simplified by the sub-division of tasks into different functions, which were called in the main function as laid out in Figure 4. This sub-division made the delegation of tasks easier and improved the readability of the code. It also simplified the writing and testing of the code, as any errors could easily be isolated to the specific function causing those errors. This subdivision included 4 general categories, each with several functions: high level functions, calculation functions, one-time functions, and movement functions. These functions are laid out in *Table 1: List of Functions*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Function Name** | **Return Type** | **Parameters** | **Function Description** | **Programmer** |
| **High Level Functions** | | | | |
| followLine() | void | &drop\_index, &domino\_count | Follows a line on the ground while dropping dominoes (see Figure 6) | Sean |
| followPathFromFile() | void | &drop\_index, &domino\_count | Follows a set of instructions predetermined by the user while dropping dominoes (see Figure 7) | Andor |
| getInstrFromFile() | int | &all\_instr | Loads a set of instructions from a text file into an array of instruction objects, allowing the robot to then follow those instructions with the followPathFromFile() function | Andor |
| dropDomino() | void | &drop\_index, &domino\_count | Dispenses a domino from the hopper into the release chute, opening and closing the door as needed (see Figure 5) | Henrique |
| somethingInTheWay() | void | motor\_power | Called when an object is detected in front of the robot. Halts all operation until object is removed from in front of the robot, then sets motor speed to continue program operation | Josh |
| somethingInTheWay() | void | left\_mot\_pow, right\_mot\_pow | Does the same as above function, except sets left and right motor speeds separately, allowing this function to be called when turning | Josh |
| **Calculation Functions** | | | | |
| distToDeg() | int | dist | Converts driving distance to a degree value corresponding to motor encoder clicks | Andor |
| degToDist() | float | deg | Converts motor encoder clicks to distance driven | Andor |
| average() | float | value1, value2 | Returns average value of two separate integers | Sean |
| **One-Time Functions** | | | | |
| configureAllSensors() | void | mode | Configures sensors based on the sensors needed for selected mode (this was done to conserve battery and simplify bug fixing, as using the multiplexer often created issues) | Andor |
| selectMode() | bool |  | Allows user to select desired mode using face buttons on the Brick | Andor |
| endProgram() | void |  | Runs as the end procedure. Waits for the user to press the touch sensor. If the sensor is pressed, the robot knocks down the domino path it created, if not it exits the program. | Andor |
| **Movement Functions** | | | | |
| setDriveTrainSpeed() | void | speed | Sets the speed of drive motors | Andor |
| driveDist() | void | dist, mot\_pow | Drives specified distance without dropping dominoes | Andor |
| driveWhileDropping() | void | dist, mot\_pow, drop\_index, domino\_count, dist\_since\_last\_dom | Drives specified distance while dropping dominoes periodically, based on a set distance between dominoes | Andor |
| turnInPlace() | void | angle, mot\_pow | Turns robot in place without dispensing dominoes. Important for followPathFromFile() function | Andor |
| turnWhileDropping() | void | angle, speed, drop\_index, domino\_count, dist\_since\_last\_dom | Turns robot through a specific radius while dropping dominoes periodically, based on a set distance between dominoes | Andor |
| stopAndKnock() | void |  | Stops robot and drives backwards, knocking down the domino chain | Josh |
| openDoor() | void |  | Opens dispenser door | Henrique |
| closeDoor() | void |  | Closes dispenser door | Henrique |

Table 1: List of Functions

### 5.12 Task List

The robot was required to accomplish these specific tasks:

* Follow line
* Read and follow instructions from a file
* Drop dominoes with appropriate spacing
* Respond accordingly to button press
* Stop when an object is seen ahead

Note: as these are very general tasks, they did not change throughout the project.

### 5.13 Data Storage

Data is stored in three main general categories. Firstly, many constants are used to make adjusting specific parameters in the code very straightforward. Secondly, there are many temporary variables created throughout the code to store important values, such as the number of dominoes remaining in the hopper, or the position of the dispenser arm. Lastly, for the follow path from file mode, a structure was created to simplify the storage of instructions. Each instruction object contains a boolean representing whether the instruction is a turn or not, and a value. This value represents an angle if the instruction is a turn, or a distance if it is not. This structure is used through the use of an array, storing all the instructions for the robot to execute.

## 5.2 Decisions and Trade-Offs

The codebase was designed with modularity at the forefront. Many functions were used to isolate every separate function of the robot and simplify both the coding process and the readability of the code. While this modular design significantly lengthened the code and led to some integration bugs, the advantages it offered ultimately made the entire coding process much easier.

Aside from this, our program allowed the user to choose between two separate modes, both of which were divided into functions. This added some complexity to the program, as each mode was essentially its own separate program, however it allowed for increased flexibility in how the entire project is used. These modes also had some overlapping functionality, which meant some functions were utilised in both modes.

Another decision that was made was the decision to implement a second colour sensor, bringing the total number of sensors up to five. This required the use of a sensor multiplexer, which increased program complexity significantly and led to many obstructive software errors. Despite this, the use of a second colour sensor significantly increased the accuracy of the robot, as it no longer had to rely only on a gyro sensor (which is significantly less accurate than two colour sensors) to accomplish its line following function.

Structures were also implemented into the program, specifically to aid in the storage of instructions being imported from a text file. This increased the amount of memory each instruction consumed, decreasing the maximum instruction limit. While this was not ideal in terms of memory efficiency, it increased the readability of the code, and the instruction limit would never have been reached, as the robot would have run out of dominoes far before the instruction limit was reached.

## 5.3 Testing

Functions were tested as laid out in *Table 2: Function Testing.*

|  |  |  |  |
| --- | --- | --- | --- |
| **Function Being Tested** | **Reason For Testing** | **Expected Behaviour** | **How Correct Behaviour was Insured** |
| dropDomino() | To ensure dominoes are dispensed without falling or jamming, allowing a proper line of dominoes to be placed accurately and without falling | Domino is dispensed, robot waits for domino to stabilise and door is opened | If dominoes were placed consistently and accurately, without jamming or falling, the function was working correctly |
| driveWhileDropping() | To ensure that the robot is able to dispense dominoes with correct, consistent spacing while driving the correct distance | Robot drives specific distance while dropping dominoes at set distance intervals | If dominoes were placed with correct and consistent spacing and robot drives the distance specified, the function was working correctly |
| turnWhileDropping() | To ensure robot can consistently turn a set radius while dispensing dominoes at a rate that allows dominoes to fall in a chain when knocked over | Robot drives through a specific radius, dropping dominoes at a set interval until it has reached its target angle | If the robot drove through the entire angle, while dropping dominoes at specific, consistent intervals, the function was working correctly |
| somethingInTheWay() | To ensure robot does not knock over dominoes unintentionally, or run into obstacles during operation | Robot stops anytime an object is detected in front of it, asks user to move object while playing a sound, and continues normal operation when object is no longer detected | If the robot stopped when an object was placed in front of it and continued when the object was removed, the function was working correctly |
| stopAndKnock() | To ensure robot only knocks dominoes over when it is supposed to and does it consistently when it needs to | Robot stops and backs up until the most recently placed domino is knocked over. It then stops and ends the program. | If dominoes were consistently knocked down whenever the touch sensor was pressed, the function was working correctly |
| followPathFromFile() | To ensure path specified user is correctly translate to a domino pattern | Robot receives instructions from user through a text file and follows those instructions | If entire path was replicated, or part of the path was replicated (if robot runs out of dominoes before path is complete) in a domino path, the function was working correctly |
| followLine() | To ensure robot is able to follow and place dominoes along a given path | Robot places domino, drives following the drawn line to the right spacing, places another domino and repeats | If the line was followed and if the dominoes fell down correctly when knocked, the function was working correctly |
| main() | To ensure all functions are working together properly and all tasks are met | Robot completes all tasks outlined above without knocking dominoes down unintentionally | If the robot followed the path specified by the user and successfully reached a specified end condition, the program was working correctly |

Table 2: Function Testing

## 5.4 Significant Problems

Significant problems were encountered in two separate instances. Firstly, the RobotC code was initially set up to receive a list of coordinates from a file and then calculate the specific angle and distance instructions locally. This however proved to be very challenging, as the application of linear algebra and other complex concepts was difficult for two reasons. First, writing in a way that was universal in that the same calculations could be used for every set of coordinates, and second, hard to verify as the natural imprecision of the EV3 platform made results difficult to verify. As such the path generation code (written in Python) was modified to output instructions for the robot to follow instead of coordinates. This is because many of the calculations required to find instructions (mainly the angles between lines and the turning direction of the robot) were already calculated by the path generation code. The RobotC code was then also greatly simplified, as it no longer had to do complex calculations, only having to read in instructions and then follow them.

Another issue encountered was the use of the EV3 multiplexer and the reading of values from it. The multiplexer was connected to colour sensors that allowed the robot to follow the line and had to constantly be read from to allow for a smooth following of the line. However, reading from the sensors constantly caused the program to fail. This issue was solved through discussion with teaching assistants and another group which revealed that an individual sensor in the multiplexer could only be read from every five milliseconds. The code was modified to accommodate this timing, allowing the robot to read values from the colour sensor through the multiplexer. [see in appendix A].

Diagram

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Figure 6: Macro Flowchart

Diagram

Description automatically generated

Figure 7: Drop Domino Flowchart

Diagram

Description automatically generated

Figure 8: Line Follow Flowchart

Diagram

Description automatically generated

Figure 9: File Follow Flowchart

**6.0 Verification**

## 6.1 How Criteria Was Met

The criteria for the robot was to place the dominoes in a well spaced and consistent way, as well as following the designated path and responding to the other outside inputs, such as the touch sensor and the ultrasonic sensor.

To acknowledge that the criteria were met, the following test was done:

1. Initialise the program and choose the line follow mode
2. Let the robot start to follow the line and position an object in front of it and seeing if it responds accordingly to an obstacle
3. Let the robot run out of dominoes and press the touch sensor
4. Observe if the robot positioned the dominoes on the line and whether it responds correctly to the touch sensor input
5. Observe if all the dominoes were knocked down
6. Repeat the test but on file path mode

If all the answers were affirmative, the criteria was met.

## 6.2 How Constraints Were Decided

To decide on the constraints, the limitations on the mechanical design and on the software were considered. The constraints decided were:

* A domino limit of 30 dominoes
  + This limit was decided as it did not require a stronger motor to overcome the friction caused by more dominoes and allowed for smoother movement.
* A limit of 5 minutes to finish the path
  + This constraint was set because 5 minutes was the maximum amount of time allowed on demonstration day.

**7.0 Project Plan**

**7.1 Delegation**

### 7.11 Software division

The software was divided into two programs, simultaneously being worked on by group members using GitHub. The main RobotC program was split up as follows; Sean was responsible for the main line-follow function; Andor was responsible for the main file-follow function; Henrique was responsible for the dropDomino() function as well as its sub-functions, openDoor() and closeDoor(); Josh was responsible for the somethingInTheWay() function and the stopAndKnock() function. There were also a number of smaller, mostly trivial functions that were written as needed which were not assigned to any particular group member. It should be noted that the majority of these smaller functions, as well as the overall code outline, was completed by Andor. In file-follow mode, this main program received input from a second program written in Python, also by Andor, that created instructions for the robot to follow from a user-defined path.

### 7.12 Division of Mechanical Work

The division of the mechanical work was much less formal than that of the software. The robot itself was mostly worked on simultaneously by all of the group members, making suggestions and putting it together piece by piece. However, some elements were mainly constructed by single group members: the dispenser arm mechanism and much of the outer chassis were designed by Sean, the domino hopper was designed by Josh, and the door mechanism was designed by Henrique.

### 7.13 Division of Other Tasks

Other tasks such as the acquisition of materials, laying out paths for the robot to follow, creating presentation slides, and testing were all also done by the group as a whole without specific delegation.

## 7.2 Project Plan Revisions

Overall, the project plan did not change significantly over the course of the project. The only major plan revision was the moving back of the target date for having the codebase completed, from two days before the presentation, to seven days before the presentation, in order to allocate more time for testing and debugging.

## 7.3 Differences from Project Plan in Implementation

There were few differences between the project plan and what was actually done, although most of them were relatively minor. The code outline and codebase were completed sooner than planned, which allowed for more time dedicated to testing and debugging. Also, some mechanical issue were noticed and adjusted after our target deadline of having the assembly done such as the dispenser described in section [4.22]

**8.0 Conclusions**

At the outset of this project, the group set out to apply our knowledge and our skills to automate the process of creating a domino chain reaction. This process was to be completed by creating a mechanism that would push dominoes out of a hopper and down a ramp to stand them up, all while moving along a path that was either drawn out on the ground in front of it, or that was passed to the robot through a file. In the completion of the project, the robot successfully accomplished all of its stated goals.

The main criteria for success was for the dominoes to be placed over the chosen path and for those dominoes to be evenly spaced. This was accomplished by using either the colour sensors to follow the line or the Python program to follow the file path, and by taking the average of the two drivetrain motor encoders to space the dominoes. It is clear both by observation, as seen in [figure], and by the fact that the dominoes would all successfully topple when desired, that this criteria was met.

There were also two constraints on the project: firstly that the robot should be capable of placing at least thirty dominoes, and secondly that it should be able to accomplish this faster than a human. During the final demonstration, the robot was able to hold exactly thirty dominoes, all of which were placed in the allotted five minute timeframe. This clearly demonstrates that these constraints were met.

**9.0 Recommendations**

## 9.1 Mechanical Changes

If this project was to continue in the future, a mechanical redesign would include space for more dominoes, as well as placing the Brick in a different alignment, making it easier to read from the display.

## 9.2 Software Changes

Alongside the mechanical redesign, software changes would need to be made to accommodate the new mechanical design. Another change that would be appreciated is to modify the Python code to automatically scale the path, so that the path would be completed within the domino limit.

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|  |  |
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**Appendix A: Source Code**

/\*

Waterloo Engineering Expeller of Dominoes Main Program

Sean Aitken, Henrique Engelke, Josh Morcombe, and Andor Siegers

v1.7

Assumptions:

- more than 3 instructions will be in instruction file

- no more than 100 instructions will be given to the robot

- robot is fully loaded at program start, with exactly 30 dominoes

in the hopper

- door is closed, dispenser arm is all the way back at program start

- if user is selecting line follow mode, it must be placed on a line of adequate length

with white on either side

- if user is selecting file follow mode, a file of the correct format must be

loaded on the robot

Motor Ports:

A - left drive wheel

B - dispenser motor

C - gate motor

D - right drive wheel

Sensor Ports:

1 - MUX

2 - gyro

3 - touch

4 - ultrasonic

\*/

#include "PC\_FileIO.c"

#include "mindsensors-ev3smux.h"

#include "UW\_sensorMux.c"

typedef struct

{

bool is\_ang;

int val;

} Instr;

// one-time functions

void configureAllSensors(bool mode);

bool selectMode();

void endProgram();

// high level functions

void followLine(bool &drop\_index, int &domino\_count); // Sean

void followPathFromFile(bool &drop\_index, int &domino\_count); // Andor

int getInstrFromFile(Instr\* all\_instr);

void dropDomino(bool &drop\_index, int &domino\_count); // Henrique

void somethingInTheWay(int motor\_power); // stops and informs the user to move the object in the way

void somethingInTheWay (int left\_mot\_pow, int right\_mot\_pow);

// calculation functions

int distToDeg(float dist);

float degToDist(int deg);

float average(int value1, int value2);

// movement functions

void setDriveTrainSpeed(int speed);

void driveDist(float dist,int mot\_pow);

void driveWhileDropping(float dist, int mot\_pow, bool &drop\_index, int &domino\_count, float &dist\_since\_last\_dom); // Andor

void turnInPlace(int angle, int mot\_pow);

void turnWhileDropping(int angle, int speed, bool &drop\_index, int &domino\_count, float &dist\_since\_last\_dom); // Andor

void stopAndKnock(); // Josh

void openDoor();

void closeDoor();

// constants

const float WHEEL\_RAD = 2.75; // in cm

const int DOMINOS\_AT\_MAX\_LOAD = 30;

const int MAX\_INSTR = 100;

const float PIXELS\_PER\_CM = 5.0;

const float DIST\_BETWEEN\_DOMINOS = 3.75; // in cm

const float DIST\_BET\_DOM\_TURNING = 5.5; // in cm

const int DRIVE\_SPEED = 20; // for path from file mode

const int DIST\_IN\_FRONT\_LIM = 20; // in cm

const float TURN\_RAD = 20; // in cm - needs to be more than 6.75cm

const int TIME\_TO\_PRESS = 10; // in seconds

const int DOOR\_ANG = 90; // degrees

const int DOOR\_SPEED = 50;

const int DROP\_WAIT = 500; // in milliseconds

const int MUX\_WAIT = 10;

const int DISPENSER\_SPEED = -30;

const int DISPENSER\_POS0 = 80;

const int DISPENSER\_POS1 = -370;

const int DISPENSER\_POS2 = -530;

const int KNOCK\_SPEED = -15;

// port assignments

const int TOUCH\_PORT = S2;

const int GYRO\_PORT = S3;

const int MULTIPLEXER\_PORT = S1;

const int ULTRASONIC\_PORT = S4;

const int RIGHT\_MOT\_PORT = motorD;

const int LEFT\_MOT\_PORT = motorA;

const int DOOR\_MOT\_PORT = motorB;

const int DISPENSER\_MOT\_PORT = motorC;

task main()

{

// initialization for domino dropping

nMotorEncoder(DISPENSER\_MOT\_PORT) = 0;

nMotorEncoder(DOOR\_MOT\_PORT) = 0;

bool drop\_index = false; // false for back position, true for middle position

int domino\_count = DOMINOS\_AT\_MAX\_LOAD;

if(selectMode())// false for line follow, true for file path

{

followPathFromFile(drop\_index, domino\_count);

}

else

{

followLine(drop\_index, domino\_count);

}

}

// \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* one-time functions \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

void configureAllSensors(bool mode)

{

SensorType[TOUCH\_PORT] = sensorEV3\_Touch;

SensorType[GYRO\_PORT] = sensorEV3\_Gyro;

wait1Msec(50);

SensorType[ULTRASONIC\_PORT] = sensorEV3\_Ultrasonic;

wait1Msec(50);

SensorMode[GYRO\_PORT] = modeEV3Gyro\_Calibration;

wait1Msec(50);

SensorMode[GYRO\_PORT] = modeEV3Gyro\_RateAndAngle;

wait1Msec(50);

// if line follow mode is selected, configure sensors required for

// this mode

if(!mode)

{

SensorType[MULTIPLEXER\_PORT] = sensorEV3\_GenericI2C;

wait1Msec(100);

if (!initSensorMux(msensor\_S1\_1, colorMeasureColor))

{

displayString(2,"Failed to configure colour1");

return;

}

wait1Msec(50);

if (!initSensorMux(msensor\_S1\_2, colorMeasureColor))

{

displayString(4,"Failed to configure colour2");

return;

}

wait1Msec(50);

}

}

bool selectMode()

{

displayTextLine(5, "Choose Mode");

displayTextLine(7, "Left - Follow Line");

displayTextLine(9, "Right - Follow Path from File");

while(!getButtonPress(buttonLeft) && !getButtonPress(buttonRight))

{}

// returns true if buttonRight is pressed (path from file mode)

// returns false if buttonLeft is pressed (line follow mode)

bool mode = getButtonPress(buttonRight);

configureAllSensors(mode);

wait1Msec(700);

return mode;

}

void endProgram()

{

setDriveTrainSpeed(0);

time1[T1] = 0;

// wait for user to press touch sensor

while(time1[T1] < TIME\_TO\_PRESS\*1000)

{

if(SensorValue[TOUCH\_PORT])

stopAndKnock();

}

stopAllTasks();

}

// \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* high level functions \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

void followLine(bool &drop\_index, int &domino\_count) // Sean

{

time1[T2] = 0;

int index = 0;

int index2 = 0;

int sensor1 = 0;

int sensor2 = 0;

int domino\_encoder\_spacing = distToDeg(DIST\_BETWEEN\_DOMINOS);

openDoor();

while((domino\_count>0)&&(SensorValue(TOUCH\_PORT) == 0))

{

if((SensorValue[ULTRASONIC\_PORT]) < (DIST\_IN\_FRONT\_LIM))

{

somethingInTheWay(0);

}

if((average(nMotorEncoder[RIGHT\_MOT\_PORT],nMotorEncoder[LEFT\_MOT\_PORT])) > domino\_encoder\_spacing)

{

dropDomino(drop\_index, domino\_count);

nMotorEncoder[RIGHT\_MOT\_PORT] = nMotorEncoder[LEFT\_MOT\_PORT] = 0;

}

motor[LEFT\_MOT\_PORT] = motor[RIGHT\_MOT\_PORT] = -10;

if(time1[T2] > index)

{

sensor1 = readMuxSensor(msensor\_S1\_1);

index = time1[T2] + MUX\_WAIT;

if(sensor1 == (int) colorBlack)

{

motor[RIGHT\_MOT\_PORT] = 0;

}

}

if(time1[T2] > index2)

{

sensor2 = readMuxSensor(msensor\_S1\_2);

index2 = time1[T2] + MUX\_WAIT + 5;

if(sensor2 == (int) colorBlack)

{

motor[LEFT\_MOT\_PORT] = 0;

}

}

}

if(SensorValue(TOUCH\_PORT))

{

stopAndKnock();

}

endProgram();

}

void followPathFromFile(bool &drop\_index, int &domino\_count) // Andor

{

Instr all\_instr[MAX\_INSTR];

float dist\_since\_last\_dom = 0;

int num\_instr = getInstrFromFile(all\_instr);

int num\_turns = 0;

int instr\_index = 0;

// drive to starting position

while(num\_turns < 2)

{

if(all\_instr[instr\_index].is\_ang)

{

num\_turns++;

turnInPlace(all\_instr[instr\_index].val, 20);

}

else

{

driveDist(all\_instr[instr\_index].val/PIXELS\_PER\_CM, 50);

}

instr\_index++;

}

while(instr\_index < num\_instr && domino\_count > 0)

{

// loop through all instructions

if(all\_instr[instr\_index].is\_ang)

{

// turn

turnWhileDropping(all\_instr[instr\_index].val, DRIVE\_SPEED, drop\_index, domino\_count, dist\_since\_last\_dom);

}

else

{

// drive length

driveWhileDropping(all\_instr[instr\_index].val/PIXELS\_PER\_CM, DRIVE\_SPEED, drop\_index, domino\_count, dist\_since\_last\_dom);

}

instr\_index++;

}

endProgram();

}

int getInstrFromFile(Instr\* all\_instr) // Andor

{

// open file and initialize variables

TFileHandle fin;

bool fileOkay = openReadPC(fin,"instr.txt");

int num\_instr = 0;

readIntPC(fin, num\_instr);

int temp\_is\_ang\_int = 0;

bool temp\_is\_ang = false;

int temp\_val = 0;

for(int read\_index = 0; read\_index < num\_instr; read\_index++)

{

// read in instruction

readIntPC(fin, temp\_is\_ang\_int);

if(temp\_is\_ang\_int == 0)

{

temp\_is\_ang = false;

}

else

{

temp\_is\_ang = true;

}

readIntPC(fin, temp\_val);

all\_instr[read\_index].is\_ang = temp\_is\_ang;

all\_instr[read\_index].val = temp\_val;

}

closeFilePC(fin);

return num\_instr;

}

void dropDomino(bool &drop\_index, int &domino\_count) // Henrique

{

setDriveTrainSpeed(0);

closeDoor();

// moves dispenser arm to next position, depending on current

// position

if (!drop\_index)

{

motor[DISPENSER\_MOT\_PORT] = DISPENSER\_SPEED;

while (nMotorEncoder(DISPENSER\_MOT\_PORT) > DISPENSER\_POS1)

{

// scan for touch press

if(SensorValue[TOUCH\_PORT])

{

motor[DISPENSER\_MOT\_PORT] = 0;

stopAndKnock();

}

}

motor[DISPENSER\_MOT\_PORT] = 0;

drop\_index = true;

wait1Msec(DROP\_WAIT);

}

else

{

motor[DISPENSER\_MOT\_PORT] = DISPENSER\_SPEED;

while (nMotorEncoder(DISPENSER\_MOT\_PORT) > DISPENSER\_POS2)

{

if(SensorValue[TOUCH\_PORT])

{

motor[DISPENSER\_MOT\_PORT] = 0;

stopAndKnock();

}

}

motor[DISPENSER\_MOT\_PORT]= 0;

drop\_index = false;

wait1Msec(100);

// reset arm to initial position

motor[DISPENSER\_MOT\_PORT] = -DISPENSER\_SPEED;

while (nMotorEncoder(DISPENSER\_MOT\_PORT) < DISPENSER\_POS0)

{

if(SensorValue[TOUCH\_PORT])

{

motor[DISPENSER\_MOT\_PORT] = 0;

stopAndKnock();

}

}

motor[DISPENSER\_MOT\_PORT] = 0;

}

openDoor();

domino\_count--;

}

void somethingInTheWay (int motor\_power) // Josh

{

// Stops motors, displays message and plays a sound. Exits when object is moved.

while(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

setDriveTrainSpeed(0);

eraseDisplay();

displayString(5, "Please clear path ahead");

playSound(soundBeepBeep);

}

ev3StopSound();

setDriveTrainSpeed(motor\_power);

}

void somethingInTheWay (int left\_mot\_pow, int right\_mot\_pow)

{

// same as apove, just with 2 motor inputs to accomodate the

// use of this function in turns

while(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

setDriveTrainSpeed(0);

eraseDisplay();

displayString(5, "Please clear path ahead");

playSound(soundBeepBeep);

}

ev3StopSound();

motor[LEFT\_MOT\_PORT] = left\_mot\_pow;

motor[RIGHT\_MOT\_PORT] = right\_mot\_pow;

}

// \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* calculation functions \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

int distToDeg(float dist)

{

// takes a distance and converts it to motor encoder clicks

// using wheel radius

return dist\*180/PI/WHEEL\_RAD;

}

float degToDist(int deg)

{

// converts degrees to motor encoder clicks using wheel radius

return deg\*PI\*WHEEL\_RAD/180;

}

float average(int value1, int value2)

{

// returns average of two fucntions

return (abs(value1 + value2)/2.0);

}

// \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* movement functions \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

void setDriveTrainSpeed(int speed)

{

// accomodates the backwards mounting of drive motors

motor[LEFT\_MOT\_PORT] = motor[RIGHT\_MOT\_PORT] = -1\*speed;

}

void driveDist(float dist, int mot\_pow)

{

// drives specified distance without dropping dominoes

setDriveTrainSpeed(mot\_pow);

nMotorEncoder[LEFT\_MOT\_PORT] = 0;

while(abs(nMotorEncoder[LEFT\_MOT\_PORT]) < distToDeg(dist))

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

stopAndKnock();

}

else if(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

somethingInTheWay(mot\_pow);

}

}

setDriveTrainSpeed(0);

}

void driveWhileDropping(float dist, int mot\_pow, bool &drop\_index, int &domino\_count, float &dist\_since\_last\_dom)

{

// drives specified distance while dropping dominos at consistent intervals

setDriveTrainSpeed(mot\_pow);

nMotorEncoder[LEFT\_MOT\_PORT] = 0;

nMotorEncoder[RIGHT\_MOT\_PORT] = 0;

while(degToDist(abs(nMotorEncoder(LEFT\_MOT\_PORT))) < dist && domino\_count > 0)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

stopAndKnock();

}

else if(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

somethingInTheWay(mot\_pow);

}

// drop domino every DIST\_BETWEEN\_DOMINOS

if(degToDist(abs(nMotorEncoder(RIGHT\_MOT\_PORT))) + dist\_since\_last\_dom >= DIST\_BETWEEN\_DOMINOS)

{

dist\_since\_last\_dom = 0;

nMotorEncoder(RIGHT\_MOT\_PORT) = 0;

dropDomino(drop\_index, domino\_count);

setDriveTrainSpeed(mot\_pow);

}

}

// allows for a smooth transition in the domino path between driving linearly and turning

dist\_since\_last\_dom = degToDist(abs(nMotorEncoder(RIGHT\_MOT\_PORT)));

}

void turnInPlace(int angle, int mot\_pow)

{

int initialGyro = getGyroDegrees(GYRO\_PORT);

if(angle < 0)

{

// turn left

motor[LEFT\_MOT\_PORT] = mot\_pow;

motor[RIGHT\_MOT\_PORT] = -mot\_pow;

while(getGyroDegrees(GYRO\_PORT) > initialGyro+angle)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

stopAndKnock();

}

else if(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

somethingInTheWay(mot\_pow, -mot\_pow);

}

}

}

else if(angle > 0)

{

// turn right

motor[LEFT\_MOT\_PORT] = -mot\_pow;

motor[RIGHT\_MOT\_PORT] = mot\_pow;

while(getGyroDegrees(GYRO\_PORT) < initialGyro+angle)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

stopAndKnock();

}

else if(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

somethingInTheWay(-mot\_pow, mot\_pow);

}

}

}

setDriveTrainSpeed(0);

}

void turnWhileDropping(int angle, int speed, bool &drop\_index, int &domino\_count, float &dist\_since\_last\_dom)

{

// some concepts taken from:

// https://math.stackexchange.com/questions/4310012/calculate-the-turning-radius-turning-circle-of-a-two-wheeled-car

// turns the robot through a specific radius while dropping dominoes

float const TURN\_RATIO = (TURN\_RAD-13.5)/TURN\_RAD;

int initialGyro = getGyroDegrees(GYRO\_PORT);

if(angle > 0)

{

// turn Right

motor[LEFT\_MOT\_PORT] = -speed;

motor[RIGHT\_MOT\_PORT] = -speed\*TURN\_RATIO;

nMotorEncoder(LEFT\_MOT\_PORT) = 0;

while(getGyroDegrees(GYRO\_PORT) < initialGyro+angle && domino\_count > 0)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

stopAndKnock();

}

else if(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

somethingInTheWay(-speed, -speed\*TURN\_RATIO);

}

if(degToDist(abs(nMotorEncoder(LEFT\_MOT\_PORT))) + dist\_since\_last\_dom >= DIST\_BET\_DOM\_TURNING)

{

// drops domino if correct spacing is reached

dist\_since\_last\_dom = 0;

nMotorEncoder(LEFT\_MOT\_PORT) = 0;

dropDomino(drop\_index, domino\_count);

motor[LEFT\_MOT\_PORT] = -speed;

motor[RIGHT\_MOT\_PORT] = -speed\*TURN\_RATIO;

}

}

dist\_since\_last\_dom = degToDist(abs(nMotorEncoder(LEFT\_MOT\_PORT)));

}

else if(angle < 0)

{

// turn left

motor[LEFT\_MOT\_PORT] = -speed\*TURN\_RATIO;

motor[RIGHT\_MOT\_PORT] = -speed;

nMotorEncoder(RIGHT\_MOT\_PORT) = 0;

while(getGyroDegrees(GYRO\_PORT) > initialGyro+angle && domino\_count > 0)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

stopAndKnock();

}

else if(SensorValue[ULTRASONIC\_PORT] < DIST\_IN\_FRONT\_LIM)

{

somethingInTheWay(-speed\*TURN\_RATIO, -speed);

}

if(degToDist(abs(nMotorEncoder(RIGHT\_MOT\_PORT))) + dist\_since\_last\_dom >= DIST\_BET\_DOM\_TURNING)

{

// drops domino if correct spacing is reached

dist\_since\_last\_dom = 0;

nMotorEncoder(RIGHT\_MOT\_PORT) = 0;

dropDomino(drop\_index, domino\_count);

motor[LEFT\_MOT\_PORT] = -speed\*TURN\_RATIO;

motor[RIGHT\_MOT\_PORT] = -speed;

}

}

dist\_since\_last\_dom = degToDist(abs(nMotorEncoder(RIGHT\_MOT\_PORT)));

}

}

void stopAndKnock() // Josh

{

// moves backwards, knocking over first domino

nMotorEncoder(LEFT\_MOT\_PORT) = 0;

setDriveTrainSpeed(KNOCK\_SPEED);

while(nMotorEncoder(LEFT\_MOT\_PORT) < distToDeg(DIST\_BETWEEN\_DOMINOS-0.5))

{}

setDriveTrainSpeed(0);

stopAllTasks();

}

void openDoor() // Henrique

{

motor[DOOR\_MOT\_PORT] = DOOR\_SPEED;

while (nMotorEncoder(DOOR\_MOT\_PORT)<DOOR\_ANG)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

motor[DOOR\_MOT\_PORT] = 0;

stopAndKnock();

}

}

motor[DOOR\_MOT\_PORT] = 0;

}

void closeDoor() // Henrique

{

if(!nMotorEncoder(DOOR\_MOT\_PORT)<5)

{

motor[DOOR\_MOT\_PORT] = -1\*DOOR\_SPEED;

while (nMotorEncoder(DOOR\_MOT\_PORT)>5)

{

// check for break conditions

if(SensorValue[TOUCH\_PORT])

{

motor[DOOR\_MOT\_PORT] = 0;

stopAndKnock();

}

}

motor[DOOR\_MOT\_PORT] = 0;

}

}

# Path calculator for Waterloo Engineering Expeller of Dominoes

# Andor Siegers

# v1.2

import math

import sys

import pygame

from pygame.locals import \*

class Point:

def \_\_init\_\_(self, x, y):

self.x = x

self.y = y

def \_\_str\_\_(self):

return f'({self.x}, {self.y})'

class Instr:

def \_\_init\_\_(self, if\_ang, val):

self.if\_ang = if\_ang

self.val = val

def \_\_str\_\_(self):

return f'{self.if\_ang}, {self.val}'

# Finds if 2 given line segments intersect or not

# From: https://www.geeksforgeeks.org/check-if-two-given-line-segments-intersect/

# Given three collinear points p, q, r, the function checks if

# point q lies on line segment 'pr'

def onSegment(p, q, r):

if ( (q.x <= max(p.x, r.x)) and (q.x >= min(p.x, r.x)) and

(q.y <= max(p.y, r.y)) and (q.y >= min(p.y, r.y))):

return True

return False

def orientation(p, q, r):

# to find the orientation of an ordered triplet (p,q,r)

# function returns the following values:

# 0 : Collinear points

# 1 : Clockwise points

# 2 : Counterclockwise

# See https://www.geeksforgeeks.org/orientation-3-ordered-points/amp/

# for details of below formula.

val = (float(q.y - p.y) \* (r.x - q.x)) - (float(q.x - p.x) \* (r.y - q.y))

if (val > 0):

# Clockwise orientation

return 1

elif (val < 0):

# Counterclockwise orientation

return 2

else:

# Collinear orientation

return 0

# returns true if the line segment 'p1q1' and 'p2q2' intersect

def doIntersect(p1,q1,p2,q2):

# Find the 4 orientations required for

# the general and special cases

o1 = orientation(p1, q1, p2)

o2 = orientation(p1, q1, q2)

o3 = orientation(p2, q2, p1)

o4 = orientation(p2, q2, q1)

# General case

if ((o1 != o2) and (o3 != o4)):

return True

# Special Cases

# p1 , q1 and p2 are collinear and p2 lies on segment p1q1

if ((o1 == 0) and onSegment(p1, p2, q1)):

return True

# p1 , q1 and q2 are collinear and q2 lies on segment p1q1

if ((o2 == 0) and onSegment(p1, q2, q1)):

return True

# p2 , q2 and p1 are collinear and p1 lies on segment p2q2

if ((o3 == 0) and onSegment(p2, p1, q2)):

return True

# p2 , q2 and q1 are collinear and q1 lies on segment p2q2

if ((o4 == 0) and onSegment(p2, q1, q2)):

return True

# If none of the cases

return False

# returns dot product

def dot(vA, vB):

return vA[0]\*vB[0]+vA[1]\*vB[1]

# returns line length

def calcLength(p1, p2):

return math.sqrt((p1.x-p2.x)\*\*2 + (p1.y-p2.y)\*\*2)

# get angle between two vectors

def getAngle(p1,p2,p3,p4):

# https://stackoverflow.com/questions/28260962/calculating-angles-between-line-segments-python-with-math-atan2

# Get nicer vector form

lineA = ((p1.x,p1.y),(p2.x,p2.y))

lineB = ((p3.x,p3.y),(p4.x,p4.y))

vA = [(lineA[0][0]-lineA[1][0]), (lineA[0][1]-lineA[1][1])]

vB = [(lineB[0][0]-lineB[1][0]), (lineB[0][1]-lineB[1][1])]

# Get dot prod

dot\_prod = dot(vA, vB)

# Get magnitudes

magA = dot(vA, vA)\*\*0.5

magB = dot(vB, vB)\*\*0.5

# Get cosine value

cos\_ = dot\_prod/magA/magB

# Get angle in radians and then convert to degrees

angle = math.acos(dot\_prod/magB/magA)

# Basically doing angle <- angle mod 360

ang\_deg = math.degrees(angle)%360

return ang\_deg

# calculate the center point of a circle tangent to 2 lines forming an angle

def calcCenterPoint(new\_point, rad, coords):

# from:

# https://stackoverflow.com/questions/51223685/create-circle-tangent-to-two-lines-with-radius-r-geometry

p1 = coords[len(coords) - 2]

p2 = coords[len(coords) - 1]

p3 = new\_point

le1 = math.sqrt((p2.x-p1.x)\*\*2 + (p2.y-p1.y)\*\*2) # length of A1-B1 segment

v1x = (p2.x-p1.x) / le1

v1y = (p2.y-p1.y) / le1

le2 = math.sqrt((p3.x-p2.x)\*\*2 + (p3.y-p2.y)\*\*2) # length of A1-B1 segment

v2x = (p3.x-p2.x) / le2

v2y = (p3.y-p2.y) / le2

R = rad

px1 = p1.x - v1y\*R

py1 = p1.y + v1x\*R

px2 = p2.x - v2y\*R

py2 = p2.y + v2x\*R

px1u = p1.x + v1y\*R

py1u = p1.y - v1x\*R

px2u = p2.x + v2y\*R

py2u = p2.y - v2x\*R

den = v1x\*v2y - v2x\*v1y

k1 = (v2y\*(px2-px1) - v2x\*(py2-py1)) / den

# k2 = (v1y\*(px2-px1) - v1x\*(py2-py1)) / den

k1u = (v2y\*(px2u-px1u) - v2x\*(py2u-py1u)) / den

# k2u = (v1y\*(px2u-px1u) - v1x\*(py2u-py1u)) / den

tx1 = p1.x + k1\*v1x

ty1 = p1.y + k1\*v1y

# tx2 = p2.x + k2\*v2x

# ty2 = p2.y + k2\*v2x

if(onSegment(p1,Point(tx1,ty1),p2)):

cx = px1 + k1\*v1x

cy = py1 + k1\*v1y

left\_turn = False

else:

cx = px1u + k1u\*v1x

cy = py1u + k1u\*v1y

left\_turn = True

# subtracts length taken from the arc from line lengths

len\_to\_sub = calcLength(p2, Point(tx1,ty1))

return Point(cx,cy), left\_turn, len\_to\_sub

def main():

# pygame specific instructions from:

# https://stackoverflow.com/questions/19780411/pygame-drawing-a-rectangle

pygame.init()

DISPLAY = pygame.display.set\_mode((700,500),0,32)

WHITE = (255,255,255)

BLUE = (0,0,255)

prev\_point = Point(0,0)

prev\_len\_to\_sub = 0

ang1 = 0

line\_count = -1

ANGLE\_TOLERANCE = 20

RADIUS\_IN\_CM = 20

PIXELS\_PER\_CM = 5

RADIUS\_IN\_PIXELS = RADIUS\_IN\_CM\*PIXELS\_PER\_CM

coords = [] # stores coordinates as point values

instructs = [] # stores instructions for robot

DISPLAY.fill(WHITE)

while True:

for event in pygame.event.get():

if (event.type == pygame.KEYDOWN and event.key == pygame.K\_ESCAPE) or event.type == QUIT:

# before program ends

file = open('instr.txt', 'w')

try:

# save instructions to file

file.write(str(len(instructs)) + "\n")

for i in range(len(instructs)):

file.write(str((int)(instructs[i].if\_ang)) + " " + str((int)(instructs[i].val)))

if i != len(instructs)-1:

file.write("\n")

except:

print("Unable to open file")

file.close()

pygame.quit()

sys.exit()

if event.type == pygame.MOUSEBUTTONDOWN:

# when mouse is pressed

x,y = pygame.mouse.get\_pos()

new\_point = Point(x,y)

# check for double click and continue if it is to avoid instructions with length 0

if(new\_point.x == prev\_point.x and new\_point.y == prev\_point.y):

continue

legal\_line = True

# new line

p1 = Point(prev\_point.x, prev\_point.y)

q1 = Point(new\_point.x, new\_point.y)

length = calcLength(new\_point, prev\_point)

if line\_count == -1:

# calculate very first angle to turn

angle = math.degrees(math.atan2(new\_point.y,new\_point.x))

ang1 = angle

elif line\_count == 0:

# calculates second angle to turn

angle = 180-getAngle(new\_point, prev\_point, Point(0,0), prev\_point)

# check if angle is negative

ang2 = math.degrees(math.atan2(new\_point.y,new\_point.x))

if ang2 < ang1:

angle = -angle

else:

# check if new line lintersects with any other line

angle = getAngle(new\_point, prev\_point, coords[line\_count-1], prev\_point)

# check if angle between old and new line is more than 20 degrees

if angle < ANGLE\_TOLERANCE:

legal\_line = False

for i in range(line\_count-1):

# temp line

p2 = coords[i]

q2 = coords[i+1]

if(doIntersect(p1, q1, p2, q2)):

legal\_line = False

if legal\_line:

# if all checks are passed

if line\_count != -1:

# draws line to visualize path

pygame.draw.aaline(DISPLAY, BLUE, (prev\_point.x, prev\_point.y), (new\_point.x, new\_point.y))

if line\_count >= 1:

angle = 180-angle

# calculates turn direction, while getting data to draw circle(representing turning arc)

centCoord, left\_turn, len\_to\_sub = calcCenterPoint(new\_point, RADIUS\_IN\_PIXELS, coords)

# adjust angle depending on turn direction

if left\_turn:

angle = -angle

# subtract len\_to\_sub from overall length

length -= (len\_to\_sub + prev\_len\_to\_sub)

# subtracts length from previous instruction to accomodate new arc

if line\_count == 1 and not instructs[len(instructs) - 1].if\_ang:

instructs[len(instructs) - 1].val -= len\_to\_sub

prev\_len\_to\_sub = len\_to\_sub

# draw circle representing robot turning arc

rect = Rect(centCoord.x-RADIUS\_IN\_PIXELS, centCoord.y-RADIUS\_IN\_PIXELS, RADIUS\_IN\_PIXELS\*2, RADIUS\_IN\_PIXELS\*2)

pygame.draw.arc(DISPLAY,BLUE,rect,0,2\*math.pi, 1)

# update display

pygame.display.flip()

# add new coordinate to point list

coords.append(new\_point)

prev\_point = new\_point

# add new instruction to point list

instructs.append(Instr(True,angle))

if length > 0:

instructs.append(Instr(False, length))

line\_count += 1

# update display

pygame.display.flip()

main()

# Resources:

# http://www.pygame.org/docs/ref/draw.html#pygame.draw.line

# https://www.geeksforgeeks.org/with-statement-in-python/

# https://www.pythontutorial.net/python-basics/python-write-text-file/

# https://www.w3schools.com/python/ref\_list\_extend.asp

# https://stackoverflow.com/questions/19780411/pygame-drawing-a-rectangle

# https://stackoverflow.com/questions/3838329/how-can-i-check-if-two-segments-intersect

# https://www.geeksforgeeks.org/check-if-two-given-line-segments-intersect/

# https://stackoverflow.com/questions/28260962/calculating-angles-between-line-segments-python-with-math-atan2