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1 Progress Report

1.1 1st Iteration

Should be achieved by: July 12, 2016

- Robot moves forward exactly one cell length and turns 90 ° accurately
  This is the most important feature of our robot. By ensuring accurate movement, we limit the need to readjust in each cell.

- Robot follows right wall
  This is the algorithm needed to find the unique solution to the maze. Once movement is implemented, we can just build on top of it to collect more data as we move through the maze.

1.2 2nd Iteration

Should be achieved by: July 12, 2016

- Robot tracks its orientation and location in maze
  This is dependency for most of the other requirements. By tracking movement in the cell, we are able to know when we have reached our goal and where to store cell information in our 2-D array.

- Robot beeps when reached target

- Robot stores wall information, visited/unvisited status and orientation at entry in 2-D array.
  This is required for more advanced algorithm features we wish to implement such as having the robot not check the same wall twice and displaying current location and wall information graphically. However, we chose to implement it now because it was a major criteria requirement.

1.3 3rd Iteration

Should be achieved by: July 19, 2016

- Robot returns with shortest path
  Since we know the route we took to get to our final location, we can now implement the cancelling algorithm (described in detail at **section 3.16**).

- Robot displays current location graphically on screen
  We implemented this now so that we could more easily test our algorithm. The last project feature we wanted to implement was to not check the same wall twice. We thought that this would be difficult to implement and as such improved our debugging capabilities before continuing.

1.4 4th Iteration

Should be achieved by: July 26, 2016

- Improve algorithm such that robot doesn't check same wall twice
  The premise behind this optimization is that imagine that we are in a cell with a wall to the South. If we've checked that there is a wall toward the south, we know that in the cell below our current cell, there is a wall to the North. The most general case will be programmed and described in section 3. This has two major advantages: we do not have to waste time turning and we do not incur extra error because of unneeded turning.

2 Mechanical Design of MazeBot

2.1 Top Level Mechanical Structure and Specifications

Our robot needed very accurate movement in order to be successful in the maze. This criteria depends heavily on whether or not the motor encoders report accurate values to the algorithm. In order to achieve this, we had to ensure:

- The wheels do not slip
- The robot does not hit walls
- The drive system is sturdy
- The gears are securely held in place and make proper contact.

However, there is a limit to how much we can to do minimize mechanical error in movement. As a result, we will have to readjust after a certain number of cells. This is done by driving into the wall, turning 90° and driving into the wall again. However, having to readjust too often is problematic as this adds time to our average time in each cell which is a major criteria point. As a result, we hope to minimize the amount of times we need to readjust by maximizing the accuracy of the mechanical system.

2.2 First Iteration

- **Goals:**
  - Able to go 3 cells without needing to readjust
  - Able to turn 90° accurately.

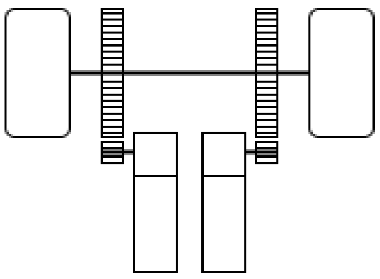


Figure 1: First Iteration Drive System

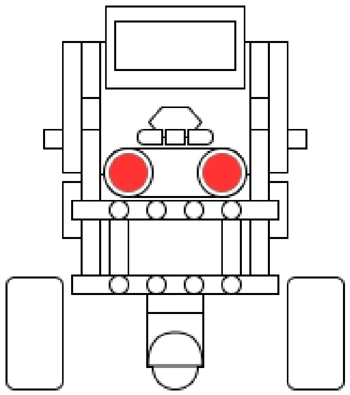


Figure 2: First Iteration Front View

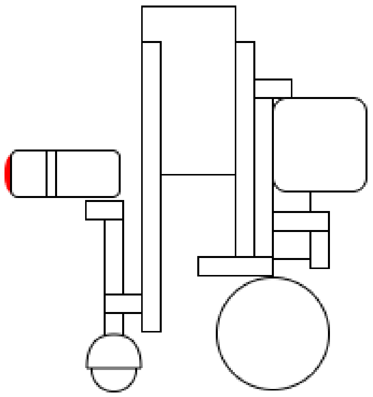


Figure 3: First Iteration Side View

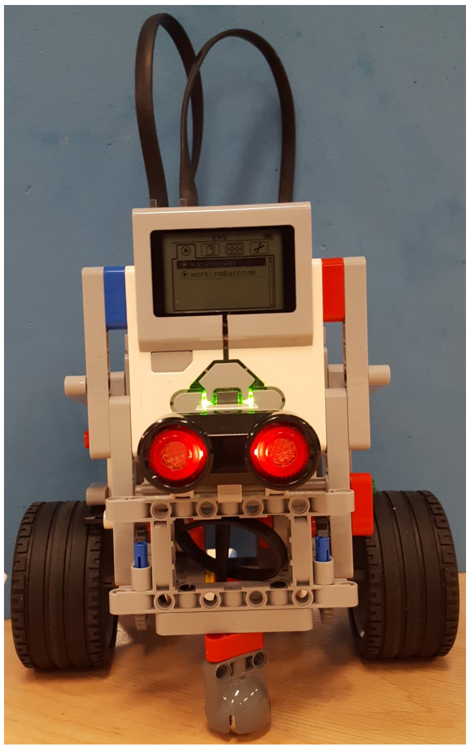


Figure 4: First Iteration Front View

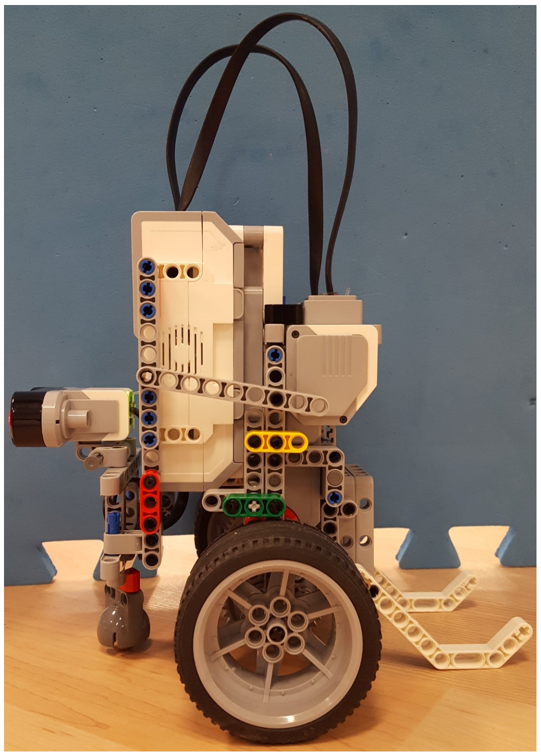


Figure 5: First Iteration Side View

- **Observations & Measurements**
  - **Goal**: Able to go 3 cells without needing to readjust
  - **Failed**: Needed to readjust every second cell
  - **Goal**: Able to turn 90° accurately.
    Test - An error of even ±1° will cause accumulate to a significant error when traversing cells. However, error in turning is hard to notice. Therefore, we chose to have robot turn 90° 8 times in place in order to propogate any error significantly.
  - **Failed**: Robot had error of ±20°

- **Reasons for Test Failures**
  - **Structural Integrity of the Drive System**
    In order for more accurate movement, we added a high gear ratio. However, since we added the high gear ratio, we are unable to find space to properly secure the left and right drive wheels. When testing, we found one wheel to slipped forward and the other to slipped back when turning which defeats the accuracy of the encoder. Because of this, we are unable to meet our goal of accurate movement.
  - **Robot is too large.**
    Since the brick is upright, it is top heavy. We needed two rods in the back and one metal ball in the front in order to balance the robot. The additions of the two rods and one metal ball negates the spacial advantage of having the robot's brick be upright. Even though the dimensions of the robot are within the size of one square, it leaves very little room for error. As such, the robot begins to run into walls after the 2$^{\text{nd}}$ turn.
  - **Wheels are too big**
    In order for the motor encoder to be accurate, the wheels must not slip. In order to maximize friction, we decided to use the largest wheels in the set. However. the extra friction with the ground from the larger wheels is not worth the extra size added to the robot. When we replaced the large wheels with smaller wheels, we noticed little to no change in accuracy of movement.

- **Conclusion**
  In conclusion, we have decided to no longer have our robot upright. This will allow us to have enough room to properly secure the drive system. This will allow us to ensure that the gears make proper contact and do slide forward or backward ensuring maximum encoder accuracy. By having the robot level with the table, we will be able to take out the additional support that we needed before to hold the bot upright. This will allow more room for error when turning and going into new cells.

2.3 Second Iteration

- **Goals:**
  - Able to go 3 cells without needing to readjust
  - Able to turn 90° accurately.

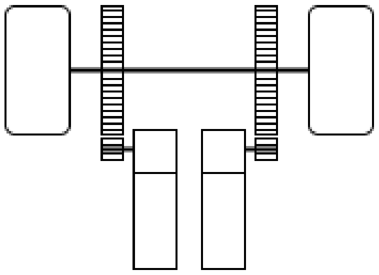


Figure 6: Second Iteration Drive System

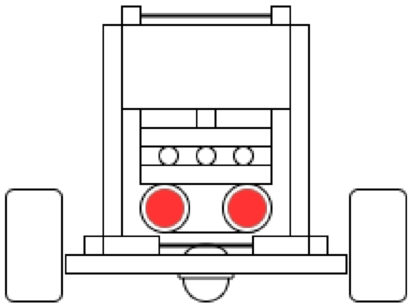


Figure 7: Second Iteration Front View

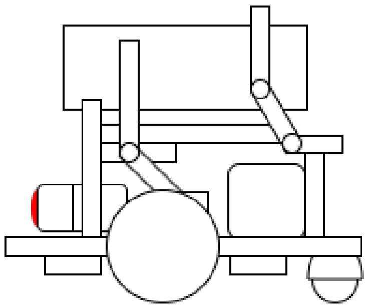


Figure 8: Second Iteration Side View

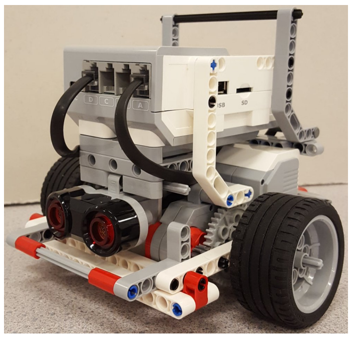


Figure 9: Second Iteration Drive System

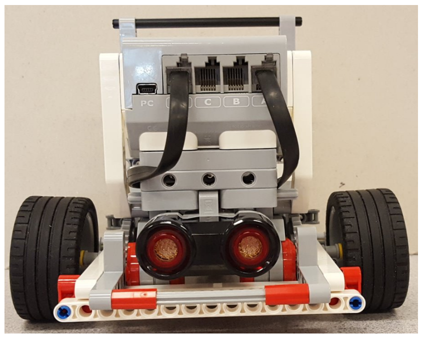


Figure 10: Second Iteration Front View

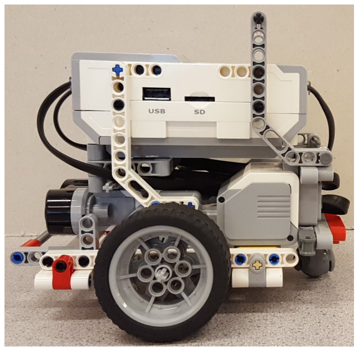


Figure 11: Second Iteration Side View

- **Observations & Measurements**
  - **Goal**: Able to go 3 cells without needing to readjust
  - **Passed**: Needed to readjust every fifth cell
  - **Goal**: Able to turn 90° accurately.
    Test - An error of even $\pm 1°$ will cause accumulate to a significant error when traversing cells. However, error in turning is hard to notice. Therefore, we chose to have robot turn 90° 8 times in place in order to propogate any error significantly.
  - **Passed**: Robot had an unnoticeable error even after eight turns
- **Reasons for Test Successes**
  Our hypotheses were correct. By securing the gears, we were able to make the motor encoders much more accurate and as a result, have the robot move in much more controlled way. Furthermore, having the robot much more compact allowed the system to have a larger tolerance for error.
- **Conclusion**
  After much contemplation, we have decided that this is the best design. The need to readjust cannot be avoided because of the uncertainty in turning caused by the legos flexing and backlash in the gears. In order to further reduce the error, we have decided to make the algorithm for the robot as efficient as possible. An examples of this is to avoid turning to check for walls as much as possible because turning is our least accurate movement.

3 Software Design of MazeBot

The main goal with the software of the mazebot was to create program that solved the problem simply and was easy to build upon. Furthermore, we wanted our software to have very few constants that we would need to tested for. For example, in order to move forward one cell, we would need to give the following function the degrees to move each of our drive motors:

```
setMotorTarget(leftMotor, degrees, 75);
```

The degrees needed to move one cell forward could be achieved by constantly testing different values of degrees to achieve the movement to the new cell. However, we chose to calculate the exact degrees that the robot's drive motors would need to move in order to move exactly one cell forward. This approach in contrast to the former has two advantages:

1. It allows us to isolate any problems with moving accurately to a mechanical problem.
2. We would not have an accumulation of error because of us testing incorrectly.

Therefore, we chose to mathematically calculate the degrees that we needed to move the motors rather than testing.

A sketch of the derivation of how many degrees to move forward is shown below:
Therefore:

```
degrees = (SIZE_OF_ONE_CELL / CIRCUMFERENCE_OF_WHEEL) * DRIVE_GEAR_RATIO * ONE_ROTATION
```

A similar derivation exists for turning the robot 90 degrees:

3.1 Variables Used to Define the Position of the Robot in the Maze and the Size of the Maze

- Two constant that represent the initial position of the robot in the maze were declared. These will be entered when we begin our demo.

```
int const START_ROW = ;
int const START_COL = ;
```

- Two constants that represents the target position in the maze were declared. These will be entered when we begin our demo.

```
int const END_ROW = ;
int const END_COL = ;
```

- Two variables that represents the current position of the robot in the maze were declared. These are initialized as the starting position.

```
int currentRow = START_ROW;
int currentCol = START_COL;
```

- An array that represents the orientation that the bot has as it enters each cell was defined. The size of the array is four times larger than the product of the maze width and maze height because the maximum amount of times that the robot can go into each cell is four times (worst case scenario).

```
int entered[MAZE_WIDTH*MAZE_HEIGHT*4];
int lastEnteredIdx = 0;
```

- A constant that represents the dimension of a single cell was defined

```
float const SIZE_OF_ONE_CELL = 22.5425; // in cm
```

- Four constants that represent the size of the maze were declared

```
int const MAZE_WIDTH = 4;
int const MAZE_HEIGHT = 6;
int const LAST_MAZE_HEIGHT_INDEX = MAZE_HEIGHT - 1;
int const LAST_MAZE_WIDTH_INDEX = MAZE_WIDTH - 1;
```

3.2 Constants and Variables Used for Representation of Directions

- The four constants that represent each of the directions were declared:

  ```
  #define NORTH 0
  #define EAST 1
  #define SOUTH 2
  #define WEST 3
  ```

- Structure name cell was declared and it has five parameters. This track where the walls are, what direction we entered from and whether we have visited the cell.

  ```
  typedef struct{
     int NWall;
     int SWall;
     int EWall;
     int WWall;
     char Visited;
     int entryDir;
  }cell;
  ```

- A 2-D array called "Maze" with the data type cell was declared. This data type is described above.

  ```
  cell Maze[MAZE_HEIGHT][MAZE_WIDTH];
  ```

3.3 Constants Used for Display

- Two constants that represent the size of the screen width and height were defined

  ```
  #define SCREEN_HEIGHT 127
  #define SCREEN_WIDTH 177
  ```

- Two constants that represent the each cell's size on the screen were defined

  ```
  #define CELL_HEIGHT (SCREEN_HEIGHT / MAZE_HEIGHT)
  #define CELL_WIDTH (SCREEN_WIDTH / MAZE_WIDTH)
  ```

- Two constants are defined which represent the robot's position in each cell in the screen

  ```
  #define CELL_HEIGHT_MIDDLE (CELL_HEIGHT / 2)
  #define CELL_WIDTH_MIDDLE (CELL_WIDTH /2)
  ```

3.4 Constants Used for Moving Mechanism

- When we calculate the degrees to move the encoder, we had two contributing errors that caused the motors to move less than they needed to. First of all, we were using integer division to find the degrees to move the motors. Therefore, the remainder is truncated and this causes the robot to move less than one cell or less than 90°. However, there is now way around this as the encoder can only move the motor forward and back by integer values. Similarily, the PID control caused the robot to move less than the desired target. Therefore, three constants were declared which are added to the encoder input values and only needed to be tested once in order to suplement the errors.

  ```
  float const UNCERTAINTY_STRAIGHT = 23;
  float const UNCERTAINTY_ROT = 28;
  float const UNCERTAINTY_READJUST = 35;
  ```

- Each speed of the motors were defined with constants for simplification of the code.

  ```
  int const FORWARD = -100;
  int const BACKWARD = -FORWARD;
  ```

- Encoder input constants were declared

  ```
  float const ONE_ROTATION = 360 + UNCERTAINTY_STRAIGHT;
  float const QUARTER_ROTATION = 180 + UNCERTAINTY_ROT;
  float const DRIVE_GEAR_RATIO = 5;
  float const DIAMETER_OF_WHEEL = 5.5; // in cm
  float const CIRCUMFERENCE_OF_WHEEL = PI * DIAMETER_OF_WHEEL;
  ```

- The amount of time that the bot will drive into the wall in order to readjust was defined. Timing algorithm was used because the flat surface at the front of the robot adjusts the bot as it drives into the wall.

  ```
  int const MILISECS_TO_DRIVE_INTO_WALL = 1100;
  ```

- A constant that represents how often the robot has to readjust its direction was defined. A gloabal variable that increases every time the robot goes into new cells to count for readjust was also defined.

  ```
  int const CELLS_TO_READJUST_AFTER = 3;
  int timesForwardWithoutReadjust = 0;
  ```

3.5 Constants Used for Representation of Wall

- A constant which represent the maximum distance possible between the robot and an object for the robot to consider it a wall.

  ```
  float const DIST_BETWEEN_BOT_AND_WALL = 7.6;
  ```

- Three constants were defined that represent the robot's knowledge of whether or not there is a wall.

  ```
  #define NOT_PRESENT 0
  #define PRESENT 1
  #define UNKNOWN 2
  ```

3.6 Constants Used for Beeping Mechanism

- A constant which represent the time and the frequency of the beep when the robot found the target

  ```
  int const MILI_TO_BEEP_FOR = 200;
  int const FREQUENCY = 300;
  ```

3.7 Displaying Function

- Function for displaying information of the robot and maze on the screen. Takes in direction and uses the maze global array.

```
void drawInfo(int direction);
```

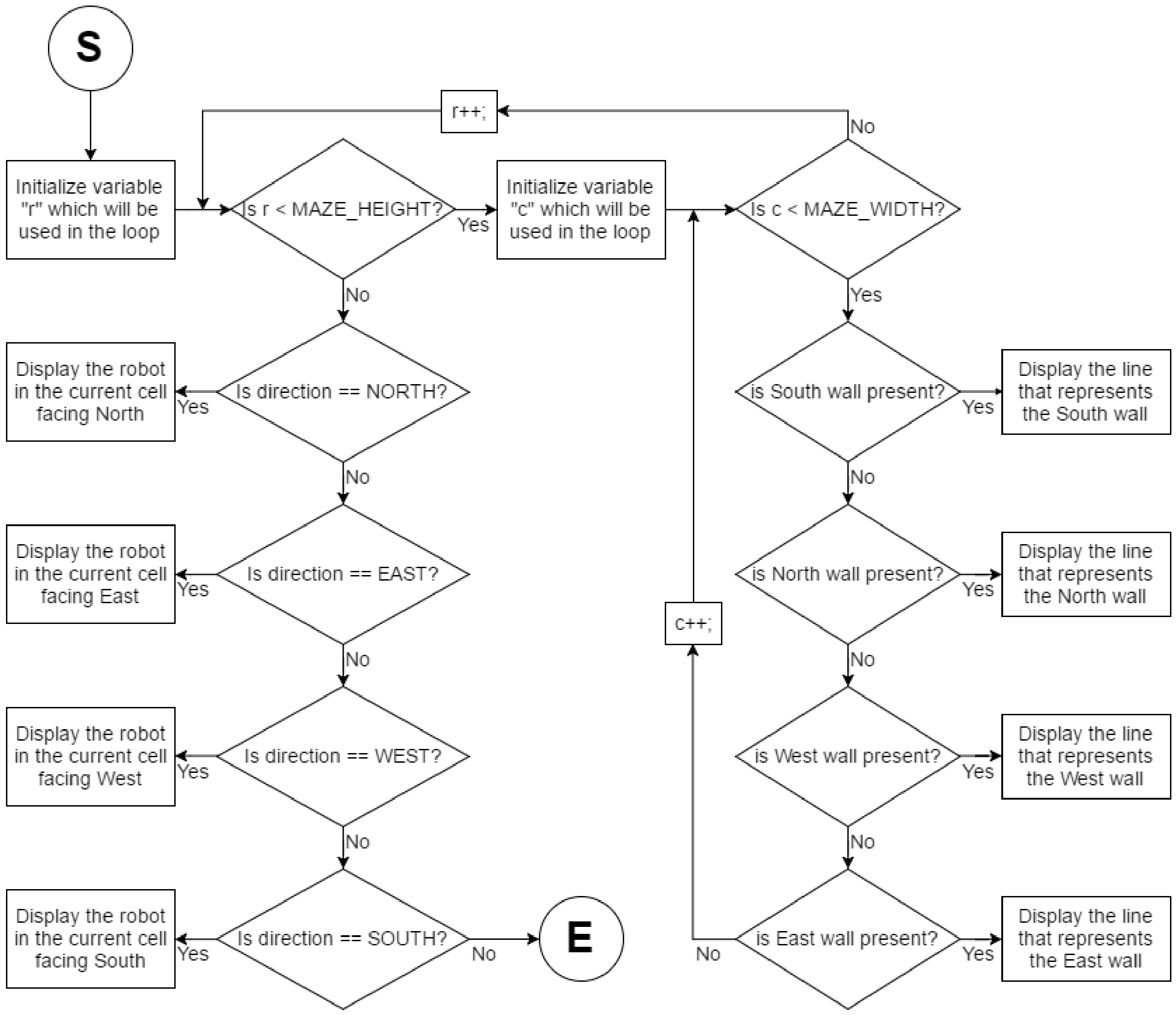

S
Initialize variable "r" which will be used in the loop
Is r < MAZE_HEIGHT?
Yes
No
r++;
Initialize variable "c" which will be used in the loop
Is c < MAZE_WIDTH?
Is direction == NORTH?
Display the robot in the current cell facing North
Is direction == EAST?
Display the robot in the current cell facing East
Is direction == WEST?
Display the robot in the current cell facing West
Is direction == SOUTH?
Display the robot in the current cell facing South
E
is South wall present?
Display the line that represents the South wall
is North wall present?
Display the line that represents the North wall
is West wall present?
Display the line that represents the West wall
is East wall present?
Display the line that represents the East wall
c++;

Figure 12: Flow Chart for Displaying Function

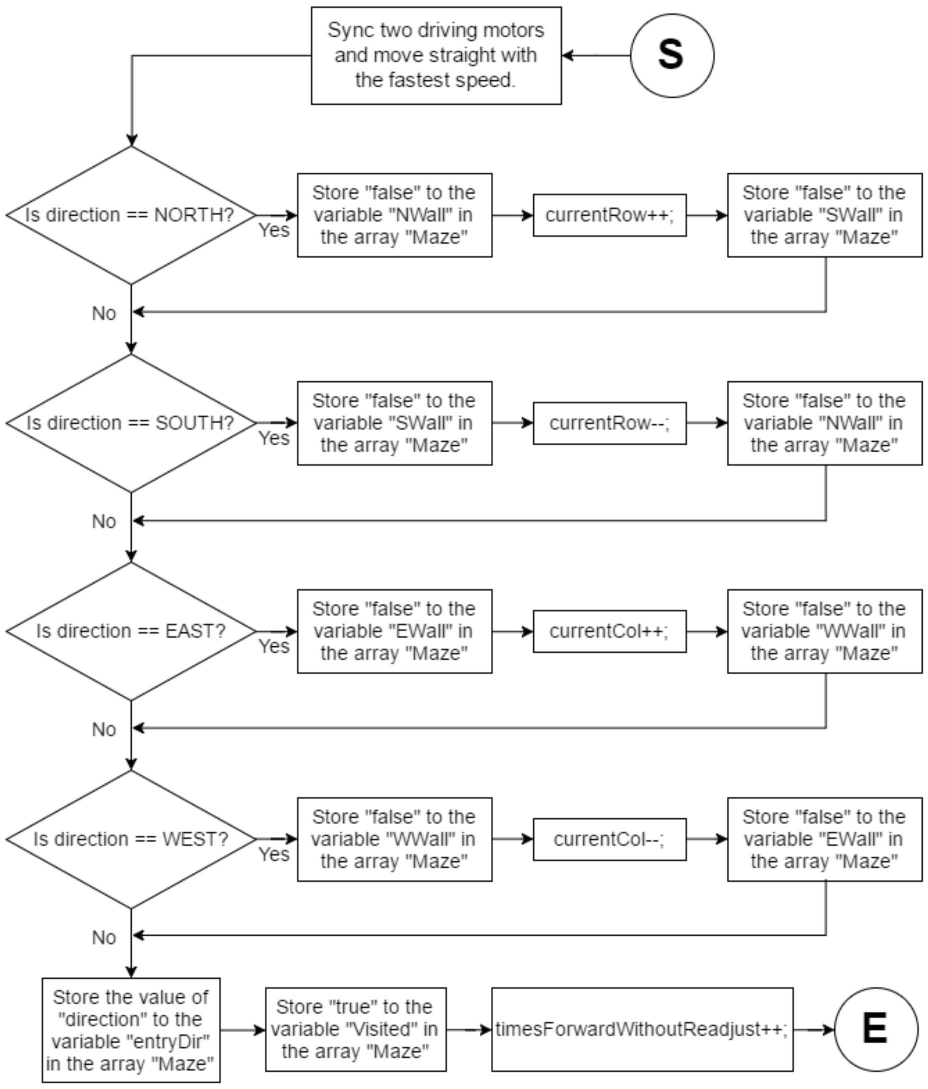
  - The local variable direction is passed into the function but it does not return any variable
  - Global variables and constants used are

```
MAZE_WIDTH
MAZE_HEIGHT
CELL_WIDTH
CELL_HEIGHT
CELL_WIDTH_MIDDLE
CELL_HEIGHT_MIDDLE
```

3.8 Moving Forward Function

- This function moves the the robot forward exactly one cell. Then, it stores the fact that there is no wall in the direction it moves. Finally, it increments how many cells it has moved without readjust.

  ```
  void goFwdCell(int direction);
  ```



S
Sync two driving motors and move straight with the fastest speed.
Is direction == NORTH?
Yes
Store "false" to the variable "NWall" in the array "Maze"
currentRow++;
Store "false" to the variable "SWall" in the array "Maze"
No
Is direction == SOUTH?
Yes
Store "false" to the variable "SWall" in the array "Maze"
currentRow--;
Store "false" to the variable "NWall" in the array "Maze"
No
Is direction == EAST?
Yes
Store "false" to the variable "EWall" in the array "Maze"
currentCol++;
Store "false" to the variable "WWall" in the array "Maze"
No
Is direction == WEST?
Yes
Store "false" to the variable "WWall" in the array "Maze"
currentCol--;
Store "false" to the variable "EWall" in the array "Maze"
No
Store the value of "direction" to the variable "entryDir" in the array "Maze"
Store "true" to the variable "Visited" in the array "Maze"
timesForwardWithoutReadjust++;
E

Figure 13: Flow Chart for Moving Forward

  - The local variable direction is passed into the function but it does not return any variable
  - Global variables and constants used are

    ```
    SIZE_OF_ONE_CELL
    CIRCUMFERENCE_OF_WHEEL
    DRIVE_GEAR_RATIO
    ONE_ROTATION
    FORWARD
    timesForwardWithoutReadjust
    Maze[][]
    ```

3.9 Turning Functions

- Function for Turning right

  `int Turn90CW(int direction);`

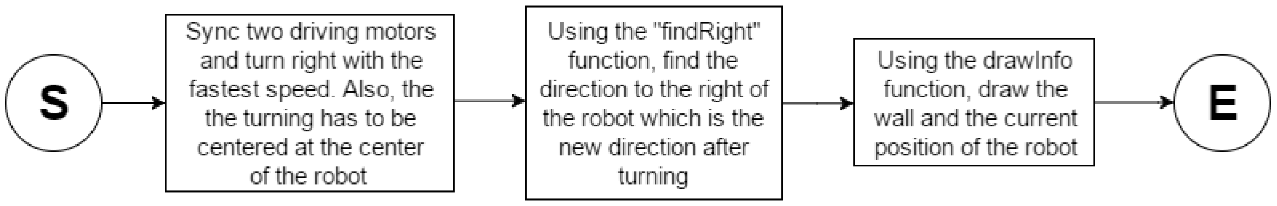

S
Sync two driving motors and turn right with the fastest speed. Also, the the turning has to be centered at the center of the robot
Using the "findRight" function, find the direction to the right of the robot which is the new direction after turning
Using the drawInfo function, draw the wall and the current position of the robot
E

Figure 14: Flow Chart for Turning Right

  - The local variable direction is passed into the function and it returns the same variable direction
  - Global variables and constants used are

    ```
    QUARTER_ROTATION;
    DRIVE_GEAR_RATIO;
    FORWARD;
    ```

  - This function calls in other functions

    ```
    int findRight(int direction);
    int drawInfo(int direction);
    ```

- Function for Turning left

  `Turn90CW(int direction);`

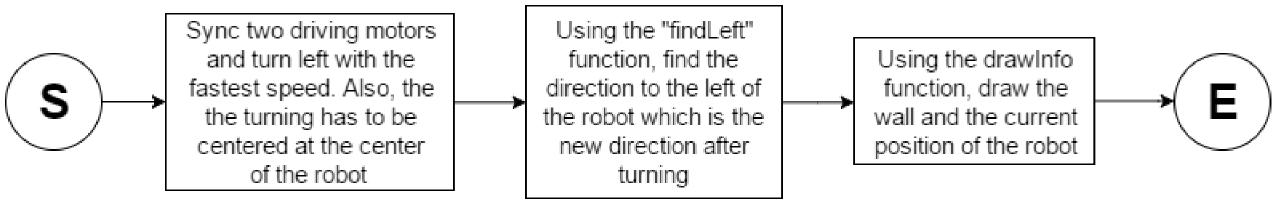

S
Sync two driving motors and turn left with the fastest speed. Also, the the turning has to be centered at the center of the robot
Using the "findLeft" function, find the direction to the left of the robot which is the new direction after turning
Using the drawInfo function, draw the wall and the current position of the robot
E

Figure 15: Flow Chart for Turning Left

  - The local variable direction is passes into the function and it returns the same variable direction
  - Global variables and constants used are

    ```
    QUARTER_ROTATION;
    DRIVE_GEAR_RATIO;
    FORWARD;
    ```

  - This function calls in other functions

    ```
    int findLeft(int direction);
    int drawInfo(int direction);
    ```

3.10 Wall Detecting Function

- Function that returns whether or not there is a wall in front of the bot.

  ```
  int thereIsWall();
  ```

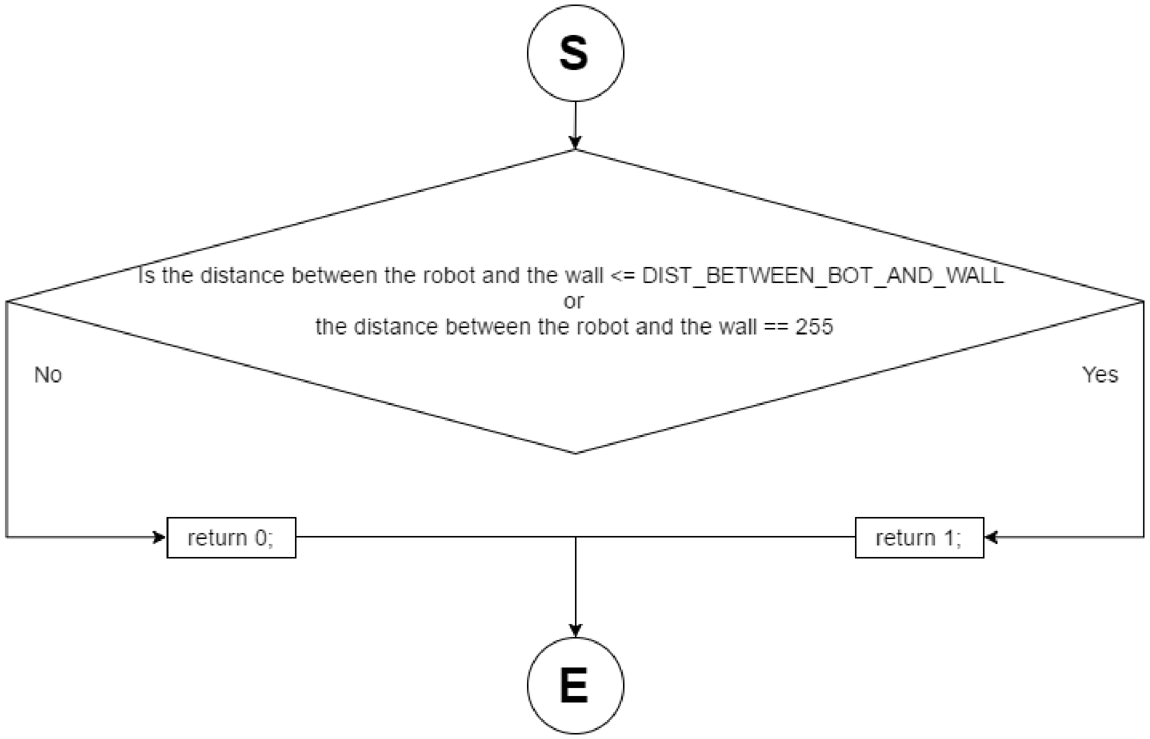

S
Is the distance between the robot and the wall <= DIST_BETWEEN_BOT_AND_WALL
or
the distance between the robot and the wall == 255
No
Yes
return 0;
return 1;
E

Figure 16: Flow Chart for Wall Detecting Function

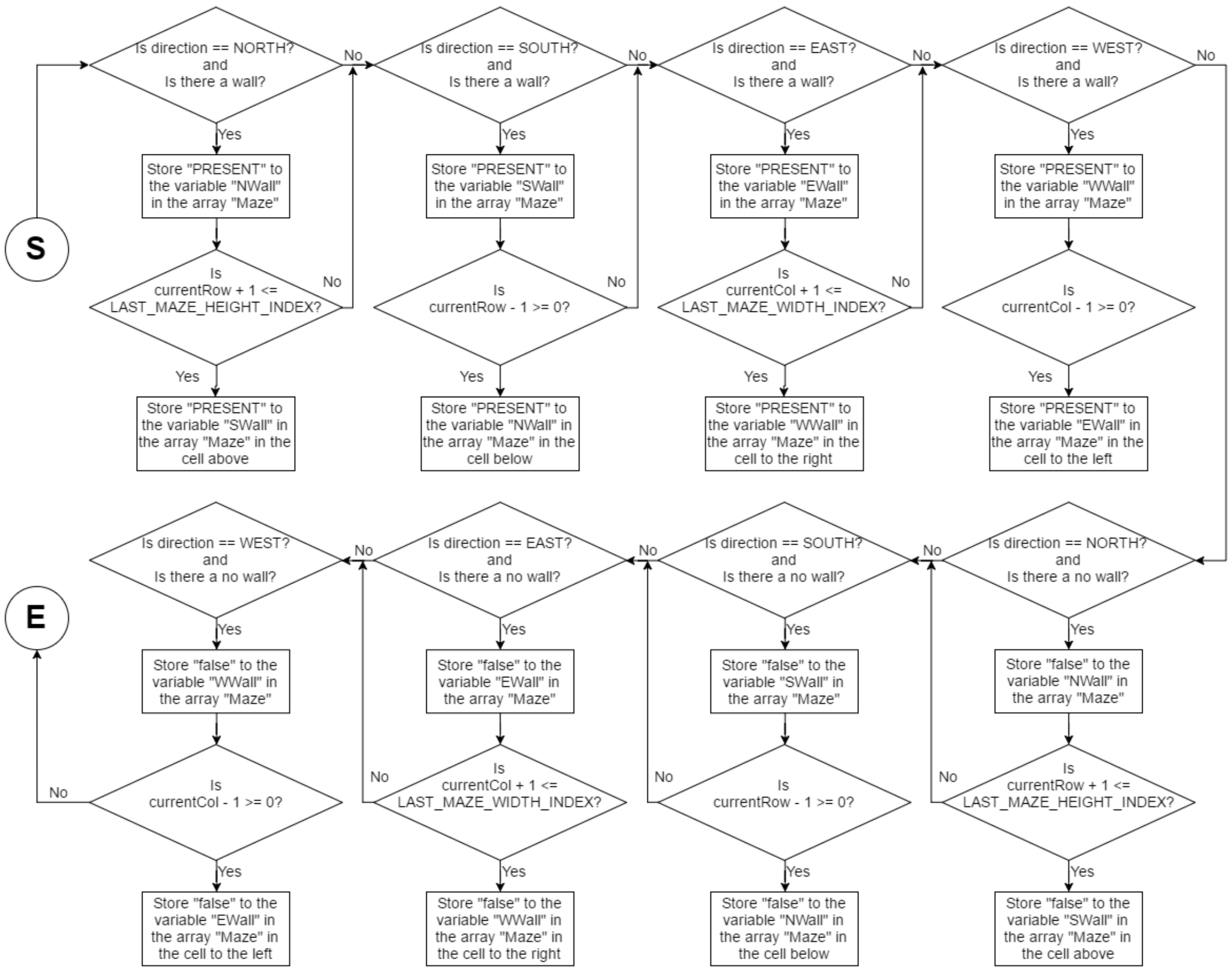
  - Very simple fuction that returns 1 if the sensor detects the wall
  - Global variables and constants used are

    `DIST_BETWEEN_BOT_AND_WALL`

3.11 Function for Storing Data of the Walls

- Function that stores data of the walls to the variables

  `void writeWall(int direction);`



S
Is direction == NORTH? and Is there a wall?
Yes
No
Store "PRESENT" to the variable "NWall" in the array "Maze"
Is currentRow + 1 <= LAST_MAZE_HEIGHT_INDEX?
Store "PRESENT" to the variable "SWall" in the array "Maze" in the cell above
Is direction == SOUTH? and Is there a wall?
Store "PRESENT" to the variable "SWall" in the array "Maze"
Is currentRow - 1 >= 0?
Store "PRESENT" to the variable "NWall" in the array "Maze" in the cell below
Is direction == EAST? and Is there a wall?
Store "PRESENT" to the variable "EWall" in the array "Maze"
Is currentCol + 1 <= LAST_MAZE_WIDTH_INDEX?
Store "PRESENT" to the variable "WWall" in the array "Maze" in the cell to the right
Is direction == WEST? and Is there a wall?
Store "PRESENT" to the variable "WWall" in the array "Maze"
Is currentCol - 1 >= 0?
Store "PRESENT" to the variable "EWall" in the array "Maze" in the cell to the left
Is direction == NORTH? and Is there a no wall?
Store "false" to the variable "NWall" in the array "Maze"
Is currentRow + 1 <= LAST_MAZE_HEIGHT_INDEX?
Store "false" to the variable "SWall" in the array "Maze" in the cell above
Is direction == SOUTH? and Is there a no wall?
Store "false" to the variable "SWall" in the array "Maze"
Is currentRow - 1 >= 0?
Store "false" to the variable "NWall" in the array "Maze" in the cell below
Is direction == EAST? and Is there a no wall?
Store "false" to the variable "EWall" in the array "Maze"
Is currentCol + 1 <= LAST_MAZE_WIDTH_INDEX?
Store "false" to the variable "WWall" in the array "Maze" in the cell to the right
Is direction == WEST? and Is there a no wall?
Store "false" to the variable "WWall" in the array "Maze"
Is currentCol - 1 >= 0?
Store "false" to the variable "EWall" in the array "Maze" in the cell to the left
E

Figure 17: Flow Chart for Storing Data Function

  - The local variable direction is passed into the function but it does not return any variable.
  - Global variables and constants used are:

    ```
    NORTH
    SOUTH
    EAST
    WEST
    currentRow
    currentCol
    PRESENT
    LAST_MAZE_HEIGHT_INDEX
    LAST_MAZE_WIDTH_INDEX
    ```

  - This function calls in other functions

    `int thereIsWall();`

3.12 Functions for setting up the direction that need to be used

- Function that takes in the current direction of the robot and returns exact opposite direction of what the robot is facing

```
int findBackDir(int currentDirection);
```

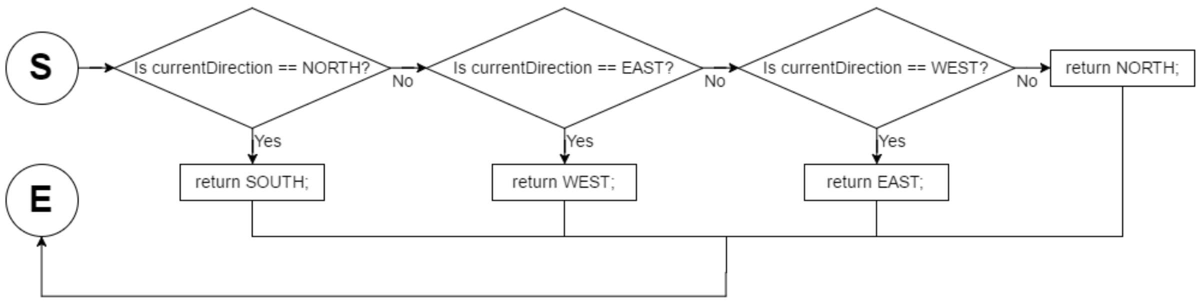

S
Is currentDirection == NORTH?
No
Yes
return SOUTH;
Is currentDirection == EAST?
No
Yes
return WEST;
Is currentDirection == WEST?
No
Yes
return EAST;
return NORTH;
E

Figure 18: Flow Chart for Finding Back Function

- Function that takes in a direction of the robot and returns the direction to the right of the robot.

```
int findRight(int currentDirection);
```

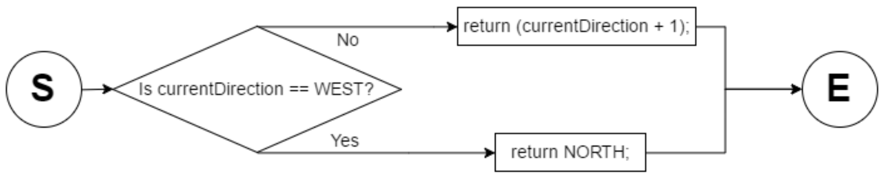


Figure 19: Flow Chart for Finding Right Function

- Function that takes in a direction of the robot and returns the direction to the left of the robot.

```
int findLeft(int currentDirection);
```

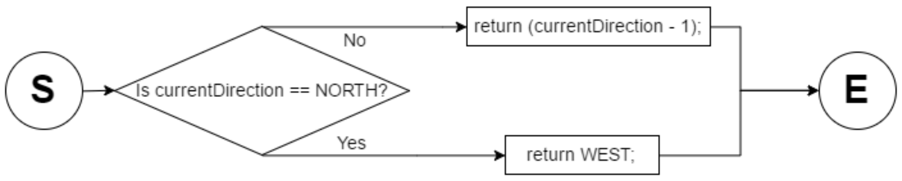


Figure 20: Flow Chart for Finding Left Function

  - Global constants used are

    ```
    NORTH
    SOUTH
    EAST
    WEST
    ```

3.13 Functions for Finding Existence of Wall from the data

- Function takes in a direction and returns whether or not there is a wall in that direction from known data.

```
int isThereWallInDir(int wallDir);
```

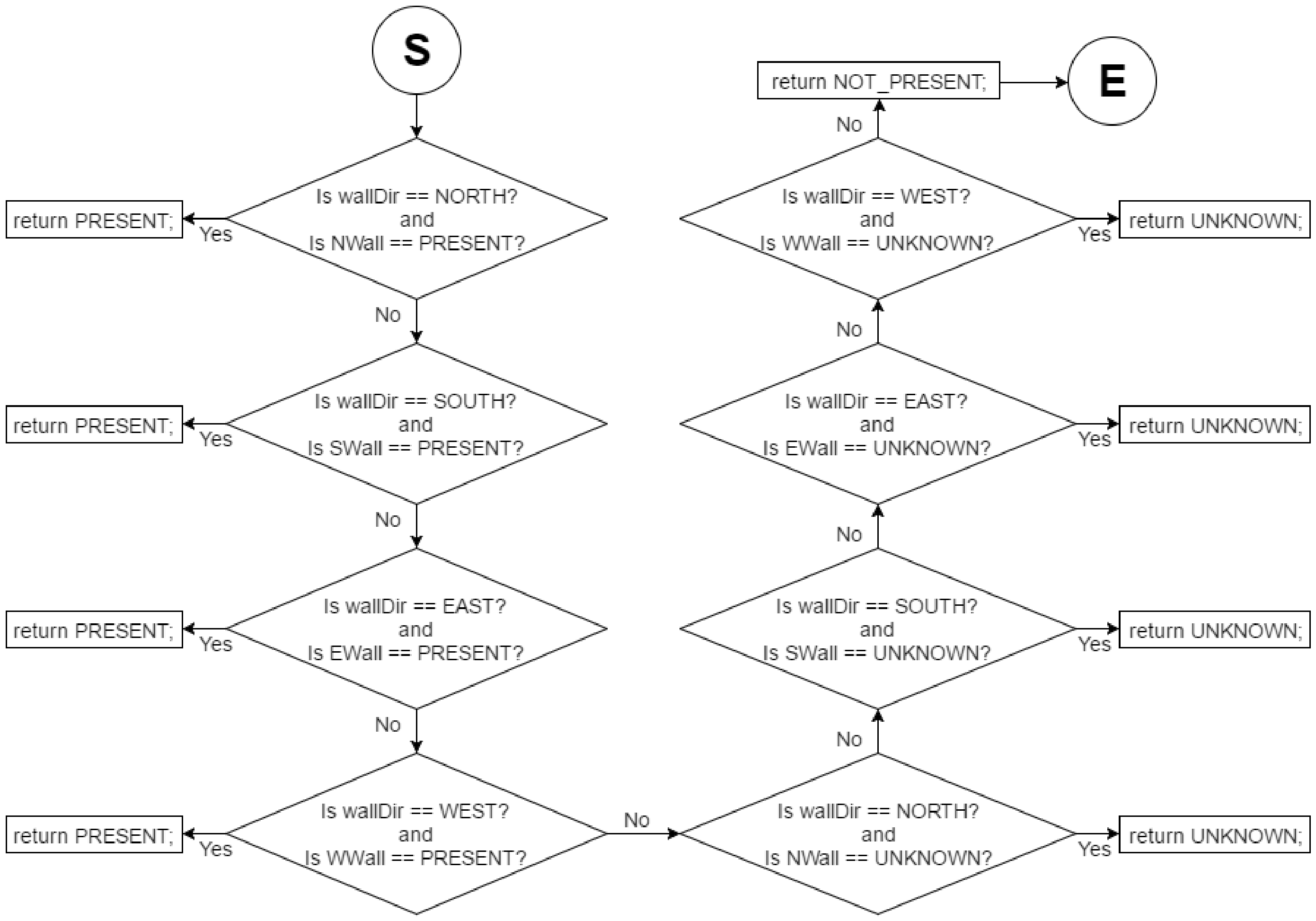

S
E
return NOT_PRESENT;
Is wallDir == NORTH? and Is NWall == PRESENT?
Is wallDir == SOUTH? and Is SWall == PRESENT?
Is wallDir == EAST? and Is EWall == PRESENT?
Is wallDir == WEST? and Is WWall == PRESENT?
return PRESENT;
Is wallDir == NORTH? and Is NWall == UNKNOWN?
Is wallDir == SOUTH? and Is SWall == UNKNOWN?
Is wallDir == EAST? and Is EWall == UNKNOWN?
Is wallDir == WEST? and Is WWall == UNKNOWN?
return UNKNOWN;
Yes
No

Figure 21: Flow Chart for Finding Existence of Wall from the data

  - Global variables and constants used are

```
NORTH
SOUTH
EAST
WEST
PRESENT
UNKNOWN
NOT_PRESENT
```

3.14 Functions for Readjusting in Certain Directions

- Function that readjusts robot's position by driving into the wall and coming back to the center of the cell. For this function particularly, we readjust using walls to the front and to the right.

  ```
  void reAdjustCW(int direction);
  ```

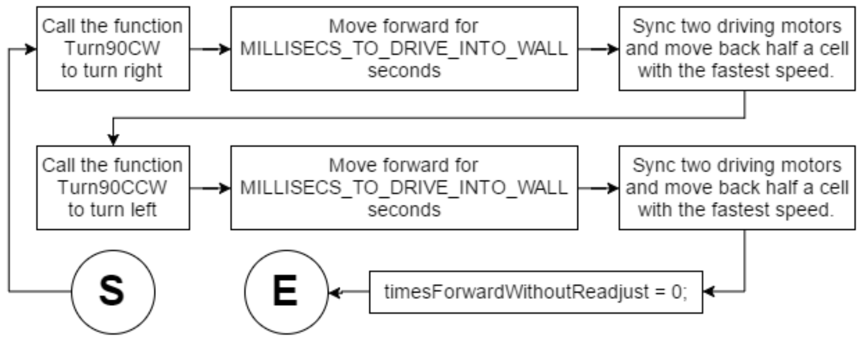

Call the function Turn90CW to turn right
Move forward for MILLISECS_TO_DRIVE_INTO_WALL seconds
Sync two driving motors and move back half a cell with the fastest speed.
Call the function Turn90CCW to turn left
Move forward for MILLISECS_TO_DRIVE_INTO_WALL seconds
Sync two driving motors and move back half a cell with the fastest speed.
S
E
timesForwardWithoutReadjust = 0;

Figure 22: Flow Chart for Readjusting using Front wall and Right wall

- Function that readjusts robot's position by driving into the wall and coming back to the center of the cell. For this function particularly, we readjust using walls to the back and to the left.

  ```
  void reAdjustCCW(int direction);
  ```

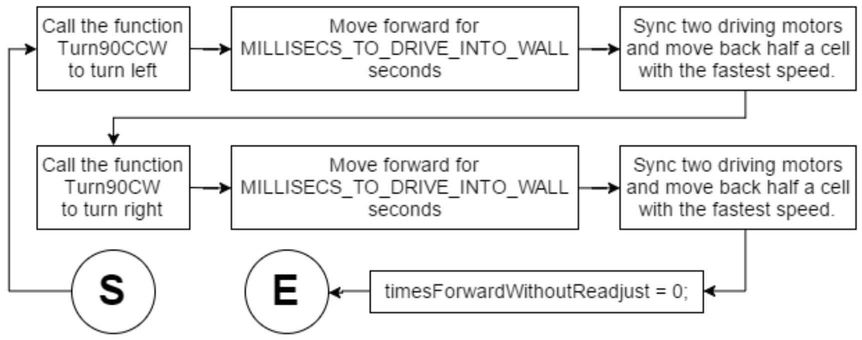

Call the function Turn90CCW to turn left
Move forward for MILLISECS_TO_DRIVE_INTO_WALL seconds
Sync two driving motors and move back half a cell with the fastest speed.
Call the function Turn90CW to turn right
Move forward for MILLISECS_TO_DRIVE_INTO_WALL seconds
Sync two driving motors and move back half a cell with the fastest speed.
S
E
timesForwardWithoutReadjust = 0;

Figure 23: Flow Chart for Readjusting using Front wall and Left wall

  - The local variable direction is passed into the function but it does not return any variable
  - Global variables and constants used are

    ```
    FORWARD
    BACKWARD
    SIZE_OF_ONE_CELL
    CIRCUMFERENCE_OF_WHEEL
    DRIVE_GEAR_RATIO
    ONE_ROTATION
    UNCERTAINTY_READJUST
    MILLISECS_TO_DRIVE_INTO_WALL
    ```

  - This function calls in other functions

    ```
    int Turn90CW(int direction);
    int Turn90CCW(int direction);
    ```

- Function that decides which direction to readjust in using the data collected in array. Once the function decides the direstion to readjust in, it cals that function.

  ```
  void reAdjustWayBack(int direction);
  ```

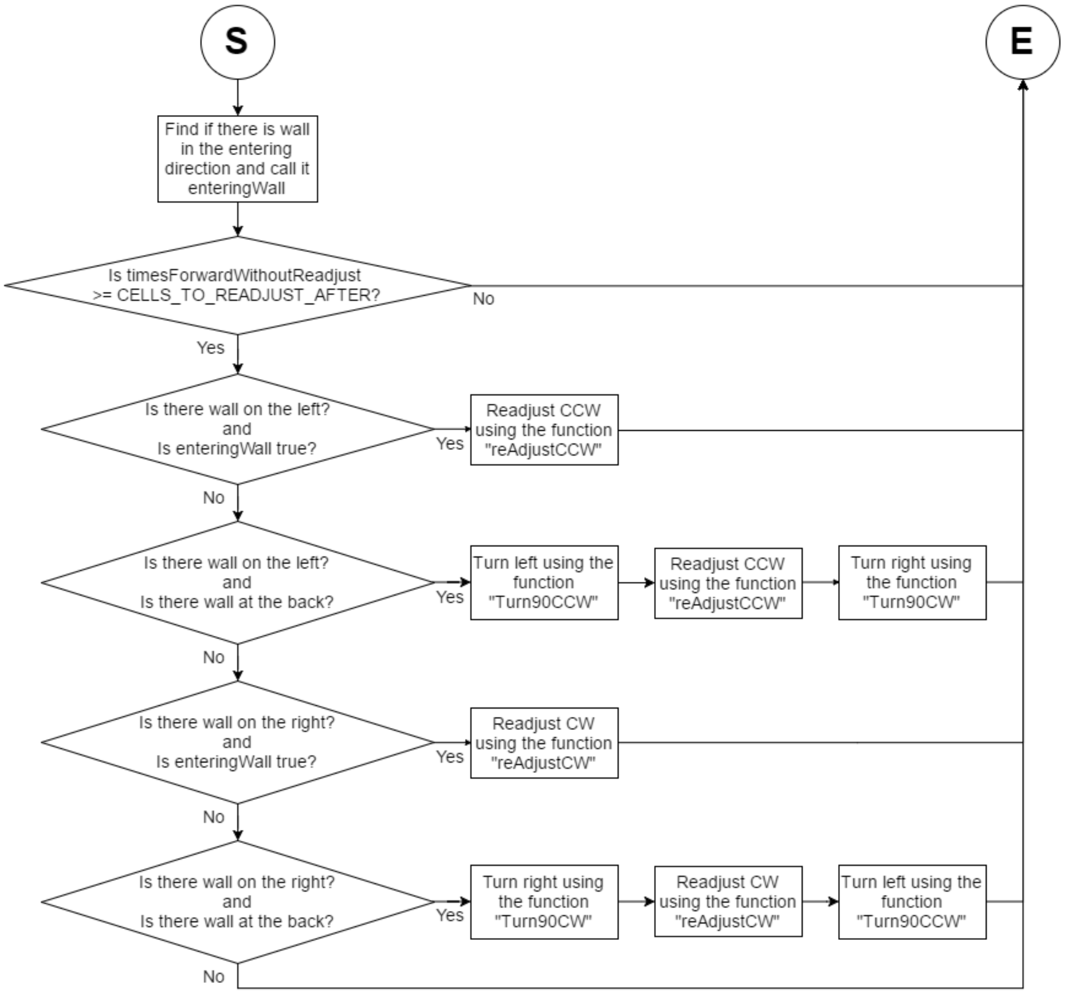

S
E
Find if there is wall in the entering direction and call it enteringWall
Is timesForwardWithoutReadjust >= CELLS_TO_READJUST_AFTER?
No
Yes
Is there wall on the left? and Is enteringWall true?
Yes
Readjust CCW using the function "reAdjustCCW"
No
Is there wall on the left? and Is there wall at the back?
Yes
Turn left using the function "Turn90CCW"
Readjust CCW using the function "reAdjustCCW"
Turn right using the function "Turn90CW"
No
Is there wall on the right? and Is enteringWall true?
Yes
Readjust CW using the function "reAdjustCW"
No
Is there wall on the right? and Is there wall at the back?
Yes
Turn right using the function "Turn90CW"
Readjust CW using the function "reAdjustCW"
Turn left using the function "Turn90CCW"
No

Figure 24: Flow Chart for Readjusting using walls detected

  - The local variable direction is passed into the function but it does not return any variable
  - Global variables and constants used are

    ```
    timesForwardWithoutReadjust
    CELLS_TO_READJUST_AFTER
    PRESENT
    ```

  - This function calls in other functions

    ```
    thereIsWall();
    reAdjustCW(int direction);
    reAdjustCCW(int direction);
    findLeft(int currentDirection);
    findRight(int currentDirection);
    findBackDir(int currentDirection);
    isThereWallInDir(int wallDir);
    ```

3.15 Function for Movement All Together

- Function that implements the right following algorithm using the functions described above. Furthermore, ensures that the robot readjusts whenever it can.

  ```
  int MovementWithSensor(int direction);
  ```

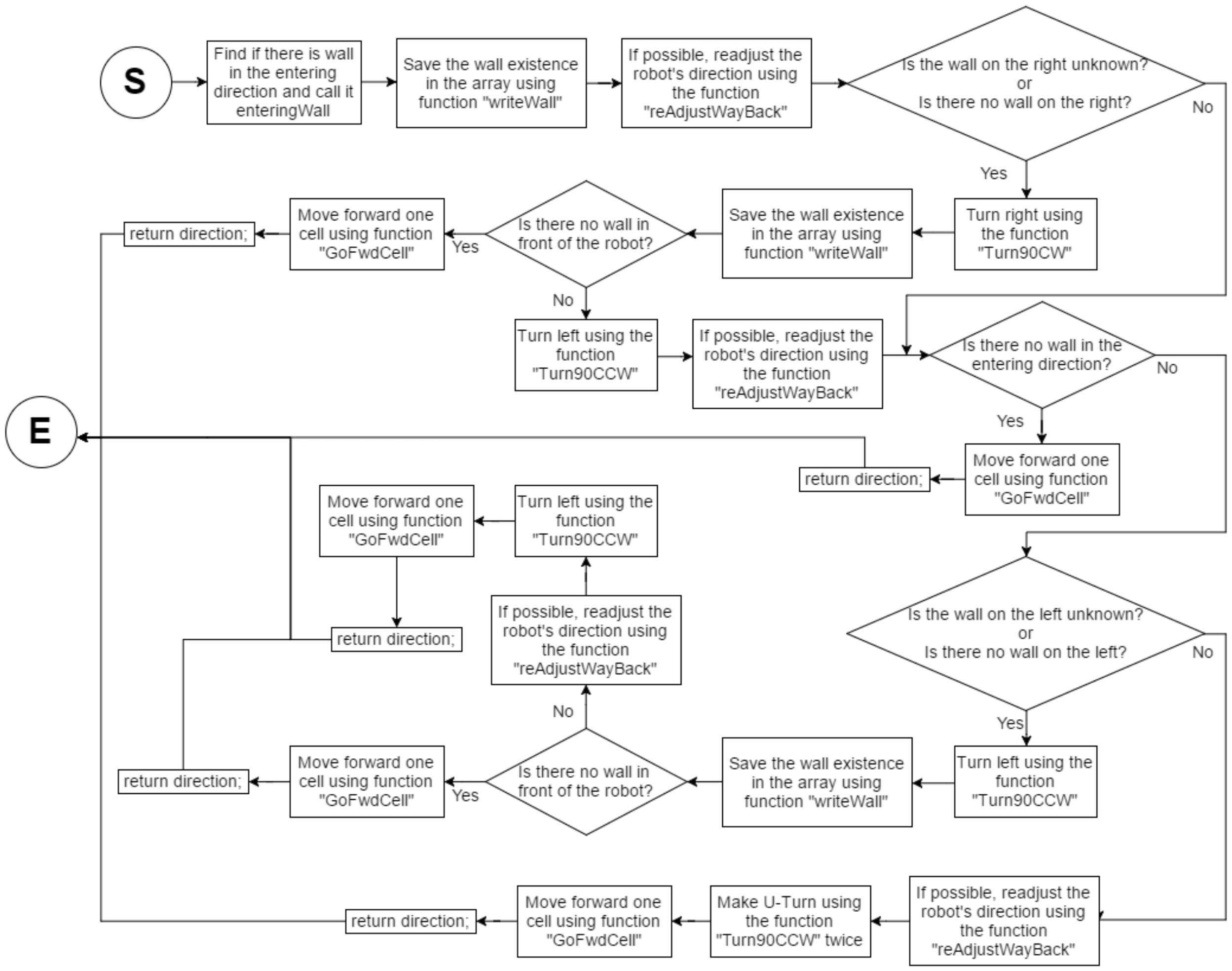

S
Find if there is wall in the entering direction and call it enteringWall
Save the wall existence in the array using function "writeWall"
If possible, readjust the robot's direction using the function "reAdjustWayBack"
Is the wall on the right unknown? or Is there no wall on the right?
Yes
No
Turn right using the function "Turn90CW"
Save the wall existence in the array using function "writeWall"
Is there no wall in front of the robot?
Yes
No
Move forward one cell using function "GoFwdCell"
return direction;
Turn left using the function "Turn90CCW"
If possible, readjust the robot's direction using the function "reAdjustWayBack"
Is there no wall in the entering direction?
Yes
No
Move forward one cell using function "GoFwdCell"
return direction;
E
Is the wall on the left unknown? or Is there no wall on the left?
Yes
No
Turn left using the function "Turn90CCW"
Save the wall existence in the array using function "writeWall"
Is there no wall in front of the robot?
Yes
No
Move forward one cell using function "GoFwdCell"
return direction;
If possible, readjust the robot's direction using the function "reAdjustWayBack"
Turn left using the function "Turn90CCW"
Move forward one cell using function "GoFwdCell"
return direction;
If possible, readjust the robot's direction using the function "reAdjustWayBack"
Make U-Turn using the function "Turn90CCW" twice
Move forward one cell using function "GoFwdCell"
return direction;

Figure 25: Flow Chart for Movement Function

  - The local variable direction is passed into the function and it returns a new variable direction.
  - Global variables and constants used are

    ```
    UNKNOWN
    NOT_PRESENT
    ```

  - This function calls the other functions

    ```
    writewall(int direction);
    reAdjustWayBack(int direction);
    isThereWallInDir(int wallDir);
    findRight(int currentDirection);
    thereIsWall();
    goFwdCell(int direction);
    Turn90CCW(int direction);
    Turn90CW(int direction);
    ```

3.16 Functions for Returning Algorithm

- Function that deletes the duplicates from the array which saved up how the robot entered each cell. For example, if the robot moved two opposite directions in order, it is not necessary. Therefore, we delete the duplicates from the array

  ```
  void deleteDuplicates();
  ```

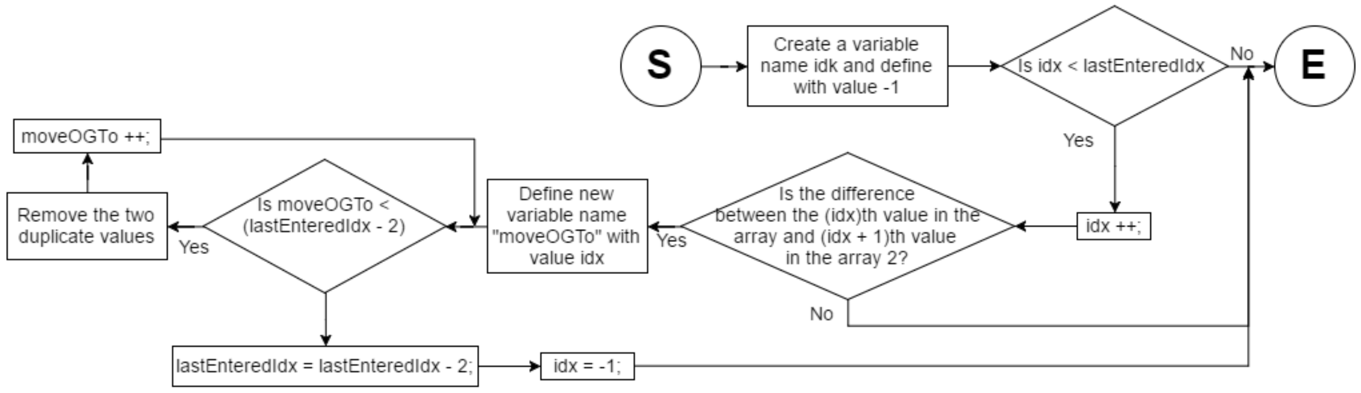

S
Create a variable name idk and define with value -1
Is idx < lastEnteredIdx
No
E
Yes
idx ++;
Is the difference between the (idx)th value in the array and (idx + 1)th value in the array 2?
No
Yes
Define new variable name "moveOGTo" with value idx
Is moveOGTo < (lastEnteredIdx - 2)
Yes
Remove the two duplicate values
moveOGTo ++;
lastEnteredIdx = lastEnteredIdx - 2;
idx = -1;

Figure 26: Flow Chart for Deleting Duplicate Function

- Function that reverses the direction from the array which saved up how the robot entered each cell. For example, if the robot went into the cell with direction East, then we change it to West. Therefore, we change all the directions to its opposite.

  ```
  void reverseDirection();
  ```

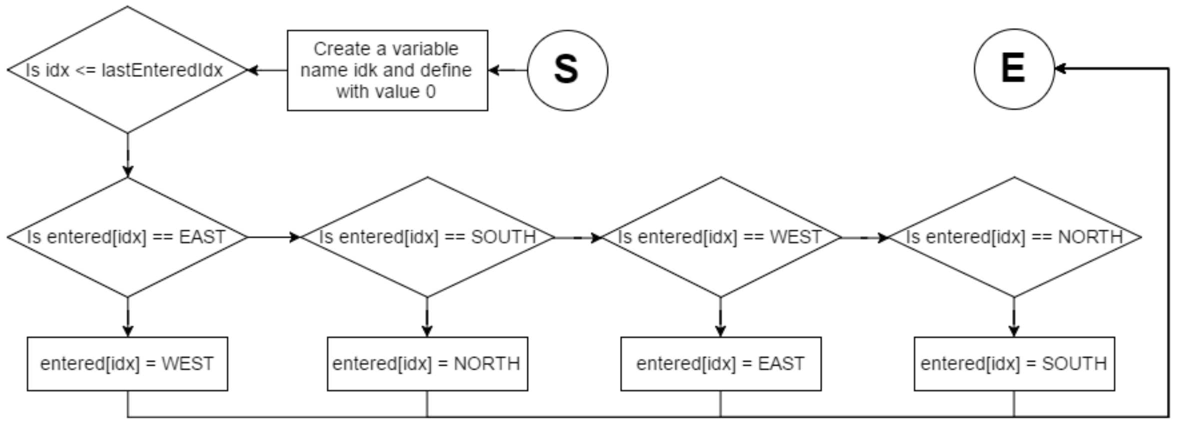


Figure 27: Flow Chart for Reversing Order of Values in the Array

- Function that takes in the variable direction and goes back to the initial position in the cell with the new array created by two functions above

  `void goingBackFastestRoute(int direction);`

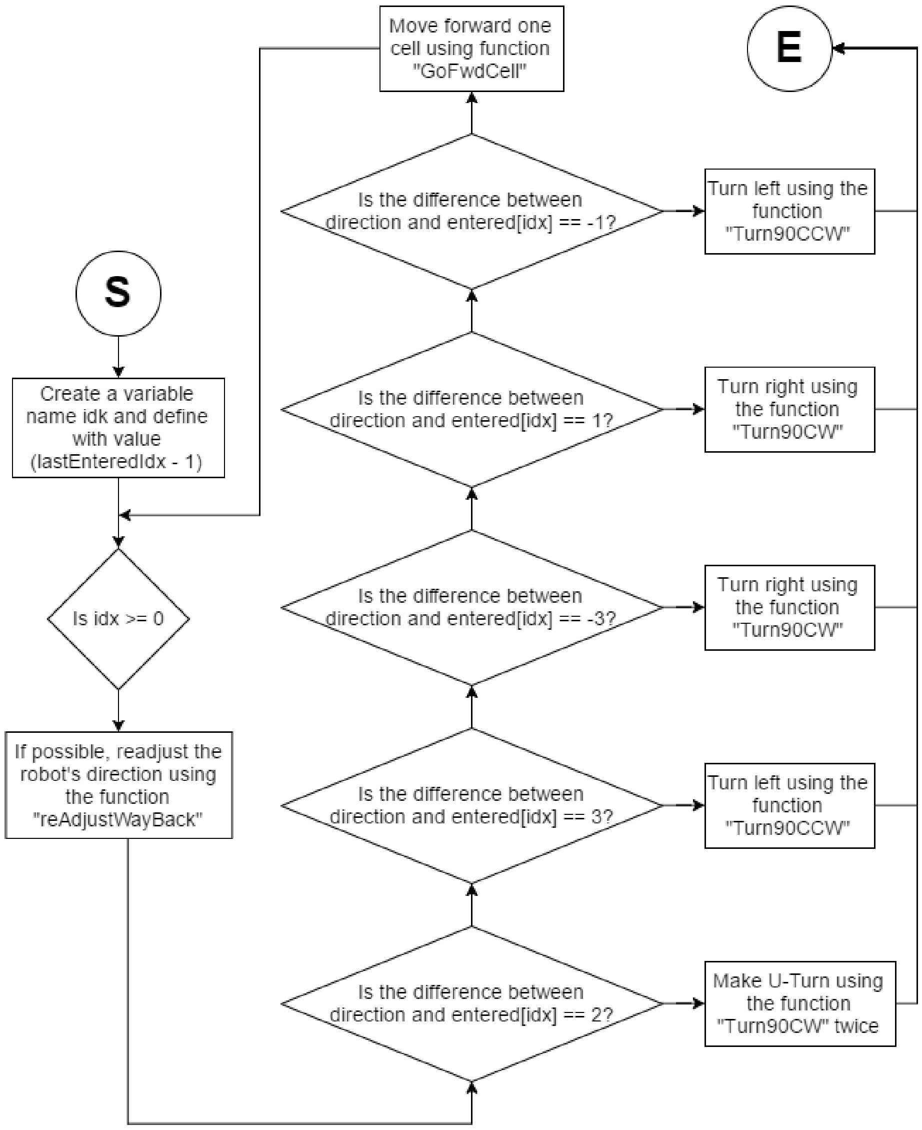

S
Create a variable name idk and define with value (lastEnteredIdx - 1)
Is idx >= 0
If possible, readjust the robot's direction using the function "reAdjustWayBack"
Is the difference between direction and entered[idx] == 2?
Make U-Turn using the function "Turn90CW" twice
Is the difference between direction and entered[idx] == 3?
Turn left using the function "Turn90CCW"
Is the difference between direction and entered[idx] == -3?
Turn right using the function "Turn90CW"
Is the difference between direction and entered[idx] == 1?
Turn right using the function "Turn90CW"
Is the difference between direction and entered[idx] == -1?
Turn left using the function "Turn90CCW"
Move forward one cell using function "GoFwdCell"
E

Figure 28: Flow Chart for Function to Go Back to Initial Position

  - Global variables and constants used are

    ```
    lastEnteredIdx
    EAST
    WEST
    SOUTH
    NORTH
    ```

  - This function calls in other functions

    ```
    reAdjustWayBack(int direction);
    Turn90CW(int direction);
    Turn90CCW(int direction);
    ```

3.17 Main Function

- More than ten functions were declared for simplicity of the main function. This function sums up all smaller functions

  ```
  task main()
  ```

  - A variable that represents current direction of the robot was declared. This is initialized as north as this is the orientation of the robot when it first enters the maze.

    ```
    int direction = NORTH;
    ```

  - Global variables and constants used are

    ```
    MAZE_WIDTH
    MAZE_HEIGHT
    UNKNOWN
    PRESENT
    lastEnteredIdx
    FREQUENCY
    MILI_TO_BEEP_FOR
    ```

  - This function calls in other functions

    ```
    MovmentWithSensor(int direction);
    deleteDuplicates();
    reverseDirection();
    goingBackFastestRoute(int direction);
    drawInfo(int direction);
    ```

- Flow chart is on the next page

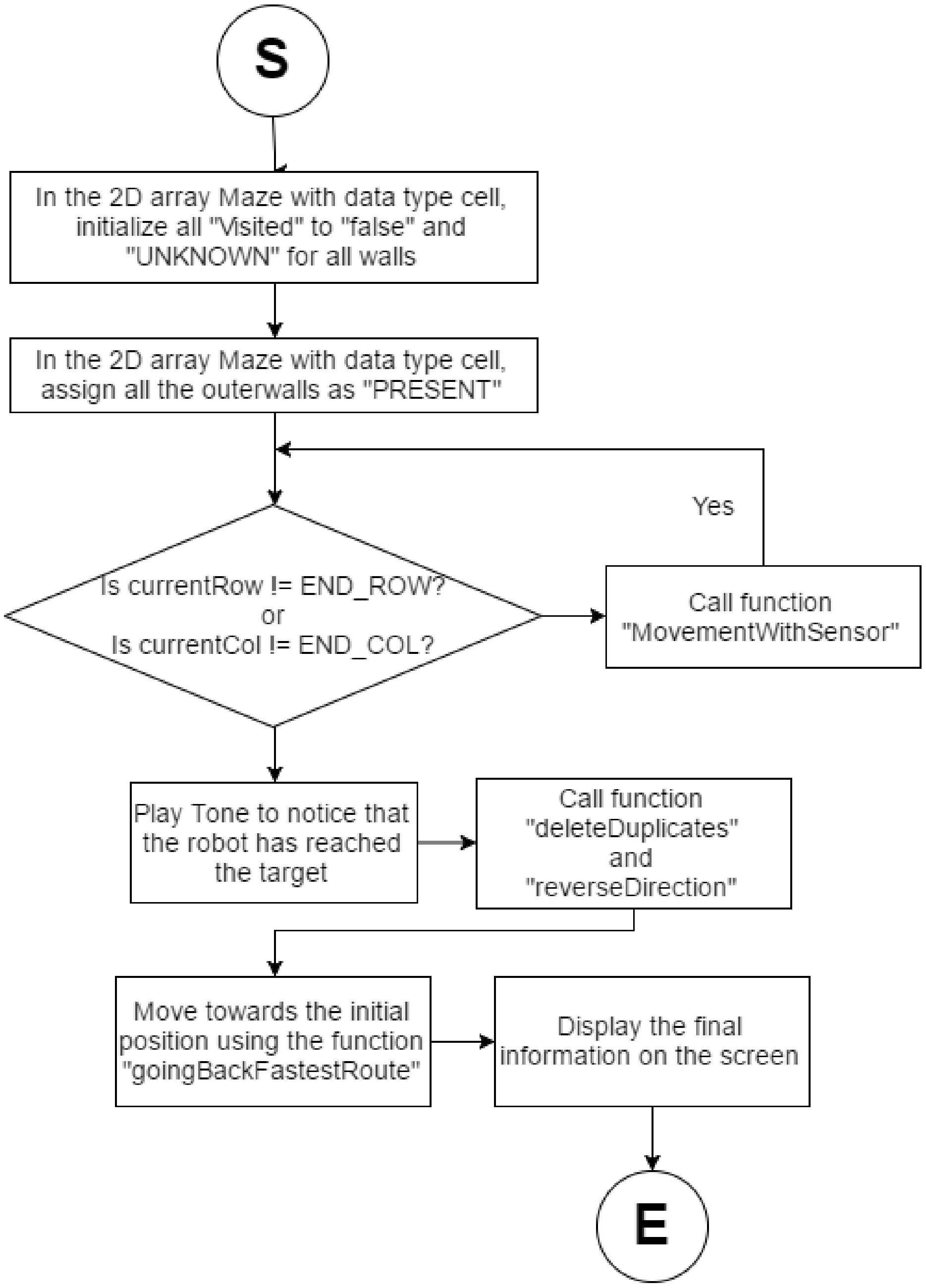

S
In the 2D array Maze with data type cell, initialize all "Visited" to "false" and "UNKNOWN" for all walls
In the 2D array Maze with data type cell, assign all the outerwalls as "PRESENT"
Yes
Is currentRow != END_ROW? or Is currentCol != END_COL?
Call function "MovementWithSensor"
Play Tone to notice that the robot has reached the target
Call function "deleteDuplicates" and "reverseDirection"
Move towards the initial position using the function "goingBackFastestRoute"
Display the final information on the screen
E

Figure 29: Flow Chart of the Main Function

4 Appendix

Code for MazeBot

```
#define NOT_PRESENT 0
#define PRESENT 1
#define UNKNOWN 2

float const DIST_BETWEEN_BOT_AND_WALL = 7.6;
// Define directions using numbers
#define NORTH 0
#define EAST 1
#define SOUTH 2
#define WEST 3

typedef struct{
int NWall;
int SWall;
int EWall;
int WWall;
int Visited;
int entryDir;
}cell;

// This is the Starting and End cell from the Demo
int const START_ROW = 2;
int const START_COL = 0;
int const END_ROW = 3;
int const END_COL = 4;
//3034 - longest route

int currentRow = START_ROW;
int currentCol = START_COL;

int const MILI_TO_BEEP_FOR = 200;
int const FREQUENCY = 300;

// Uncertainties due to integer division
float const UNCERTAINTY_STRAIGHT = 19;
float const UNCERTAINTY_ROT = 27;
float const UNCERTAINTY_READJUST = 35;

// Movement Constants defined
float const ONE_ROTATION = 360 + UNCERTAINTY_STRAIGHT;
float const QUARTER_ROTATION = 180 + UNCERTAINTY_ROT;

float const SIZE_OF_ONE_CELL = 22.5425; //cm
float const DRIVE_GEAR_RATIO = 5;
float const DIAMETER_OF_WHEEL = 5.5; // cm
float const CIRCUMFERENCE_OF_WHEEL = PI * DIAMETER_OF_WHEEL;
```

```
// Speed Variable
int const FORWARD = -100;
int const BACKWARD = -FORWARD;

// MAZE VARIABLES
int const MAZE_WIDTH = 6;
int const MAZE_HEIGHT = 4;
int const LAST_MAZE_HEIGHT_INDEX = MAZE_HEIGHT - 1;
int const LAST_MAZE_WIDTH_INDEX = MAZE_WIDTH - 1;
cell Maze[MAZE_HEIGHT][MAZE_WIDTH];

int entered[MAZE_WIDTH*MAZE_HEIGHT*4];
int lastEnteredIdx = 0;

#define SCREEN_HEIGHT 127
#define SCREEN_WIDTH 177
#define CELL_HEIGHT (SCREEN_HEIGHT / MAZE_HEIGHT)
#define CELL_WIDTH (SCREEN_HEIGHT / MAZE_WIDTH)

#define CELL_HEIGHT_MIDDLE (CELL_HEIGHT / 2)
#define CELL_WIDTH_MIDDLE (CELL_WIDTH / 2)

// MISC Constants
int const MILLISECS_TO_DRIVE_INTO_WALL = 1100;

// Call functions
void goFwdCell(int direction);
int Turn90CW(int direction);
int Turn90CCW(int direction);
int MovementWithSensor(int direction);
void reverseDirection();
void deleteDuplicates();
int goingBackFastestRoute(int direction);
void drawInfo(int direction);
void reAdjustCCW(int direction);
void reAdjustCW(int direction);
int findLeft(int currentDirection);
int findRight(int currentDirection);
int findBackDir (int currentDirection);
int isThereWallInDir(int wallDir);
void reAdjustWayBack(int direction);

int const CELLS_TO_READJUST_AFTER = 3;
int timesForwardWithoutReadjust = 0;
```

```
void drawInfo(int direction){
//drawRect(Left, Top, Right, Bottom);
eraseDisplay();

for(int r = 0; r < MAZE_HEIGHT; r++){
for(int c = 0; c < MAZE_WIDTH; c++){

if(Maze[r][c].SWall == PRESENT){
drawLine(c*CELL_WIDTH,r*CELL_HEIGHT,c*CELL_WIDTH + CELL_WIDTH,r*CELL_HEIGHT);
}
if(Maze[r][c].NWall == PRESENT){
drawLine(c*CELL_WIDTH,r*CELL_HEIGHT + CELL_HEIGHT,c*CELL_WIDTH + CELL_WIDTH,r*CELL_HEIGHT
+ CELL_HEIGHT);
}
if(Maze[r][c].WWall == PRESENT){
drawLine(c*CELL_WIDTH,r*CELL_HEIGHT,c*CELL_WIDTH, r*CELL_HEIGHT + CELL_HEIGHT);
}
if(Maze[r][c].EWall == PRESENT){
drawLine(c*CELL_WIDTH + CELL_WIDTH,r*CELL_HEIGHT,c*CELL_WIDTH + CELL_WIDTH, r*CELL_HEIGHT
+ CELL_HEIGHT);
}

}
}

if(direction == NORTH){
displayBigStringAt(currentCol*CELL_WIDTH + CELL_WIDTH_MIDDLE, currentRow*CELL_HEIGHT
+ CELL_HEIGHT_MIDDLE, "^");
}
else if(direction == EAST){
displayBigStringAt(currentCol*CELL_WIDTH + CELL_WIDTH_MIDDLE, currentRow*CELL_HEIGHT
+ CELL_HEIGHT_MIDDLE, ">");
}
else if(direction == WEST){
displayBigStringAt(currentCol*CELL_WIDTH + CELL_WIDTH_MIDDLE, currentRow*CELL_HEIGHT
+ CELL_HEIGHT_MIDDLE, "<");
}
else if(direction == SOUTH){
displayBigStringAt(currentCol*CELL_WIDTH + CELL_WIDTH_MIDDLE, currentRow*CELL_HEIGHT
+ CELL_HEIGHT_MIDDLE, "v");
}
}
```

```
task main(){

for (int c = 0; c < MAZE_WIDTH; c++){
for (int r = 0; r < MAZE_HEIGHT; r++){
Maze[r][c].Visited = false;
Maze[r][c].NWall = UNKNOWN;
Maze[r][c].SWall = UNKNOWN;
Maze[r][c].EWall = UNKNOWN;
Maze[r][c].WWall = UNKNOWN;
}
}

// Assigning walls [row][col]
for (int c = 0; c < MAZE_WIDTH; c++){
Maze[0][c].SWall = PRESENT;
Maze[LAST_MAZE_HEIGHT_INDEX][c].NWall = PRESENT;
}

for (int r = 0; r < MAZE_HEIGHT; r++){
Maze[r][0].WWall = PRESENT;
Maze[r][LAST_MAZE_WIDTH_INDEX].EWall = PRESENT;

}

int direction = NORTH;

Maze[currentRow][currentCol].entryDir = direction;
Maze[currentRow][currentCol].Visited = true;

while(currentRow != END_ROW || currentCol != END_COL){
direction = MovementWithSensor(direction);
entered[lastEnteredIdx] = direction;
lastEnteredIdx++;
}

playTone(FREQUENCY, MILI_TO_BEEP_FOR);


deleteDuplicates();

sleep(MILI_TO_BEEP_FOR * 10);

reverseDirection();
direction = goingBackFastestRoute(direction);

drawInfo(direction);

sleep(390000);
}
```

```
void deleteDuplicates(){
int idx = -1;

while(idx < lastEnteredIdx){
idx++;

if(abs(entered[idx] - entered[idx + 1]) == 2){
for(int moveOGTo = idx; moveOGTo <= lastEnteredIdx - 2; moveOGTo++){
entered[moveOGTo] = entered[moveOGTo + 2];
}

lastEnteredIdx = lastEnteredIdx - 2;
idx = -1;
}
}
}

void reverseDirection(){
for(int idx = 0; idx <= lastEnteredIdx; idx++){
if(entered[idx]==EAST){
entered[idx] = WEST;
}
else if(entered[idx]==SOUTH){
entered[idx] = NORTH;
}
else if(entered[idx]==WEST){
entered[idx] = EAST;
}
else if(entered[idx]==NORTH){
entered[idx] = SOUTH;
}
}
}

int goingBackFastestRoute(int direction){

for(int idx = lastEnteredIdx - 1; idx >= 0; idx--){
reAdjustWayBack(direction);
int turnNum = entered[idx] - direction;

if(abs(turnNum) == 2){
direction = Turn90CW(direction);
direction = Turn90CW(direction);
}
else if(turnNum == 3){
direction = Turn90CCW(direction);
}
else if(turnNum == -3){
direction = Turn90CW(direction);
}
else if(turnNum == 1){
```

```
direction = Turn90CW(direction);
}
else if(turnNum == -1){
direction = Turn90CCW(direction);
}

goFwdCell(direction);

}

return direction;
}

void goFwdCell(int direction){
setMotorSyncEncoder(leftDrive, rightDrive, 0, (SIZE_OF_ONE_CELL / CIRCUMFERENCE_OF_WHEEL)*DRIVE_GE

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}
if (direction == NORTH){
Maze[currentRow][currentCol].NWall = false;
currentRow++;
Maze[currentRow][currentCol].SWall = false;
}
else if (direction == SOUTH){
Maze[currentRow][currentCol].SWall = false;
currentRow--;
Maze[currentRow][currentCol].NWall = false;
}
else if (direction == EAST){
Maze[currentRow][currentCol].EWall = false;
currentCol++;
Maze[currentRow][currentCol].WWall = false;
}
else if (direction == WEST){
Maze[currentRow][currentCol].WWall = false;
currentCol--;
Maze[currentRow][currentCol].EWall = false;
}

Maze[currentRow][currentCol].entryDir = direction;
Maze[currentRow][currentCol].Visited = true;

timesForwardWithoutReadjust++;
}
```

```
int Turn90CCW(int direction){
setMotorSyncEncoder(leftDrive, rightDrive, -100, QUARTER_ROTATION * DRIVE_GEAR_RATIO, FORWARD);

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}

direction = findLeft(direction);

drawInfo(direction);
return direction;

}

int Turn90CW(int direction){
setMotorSyncEncoder(leftDrive, rightDrive, 100, QUARTER_ROTATION * DRIVE_GEAR_RATIO, FORWARD);

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}

direction = findRight(direction);

drawInfo(direction);
return direction;
}

int thereIsWall(){
if(getUSDistance(distance)<=DIST_BETWEEN_BOT_AND_WALL || getUSDistance(distance)==255){
return 1;
}

return 0;
}

void writeWall(int direction){
if(direction == NORTH && thereIsWall()){
Maze[currentRow][currentCol].NWall = PRESENT;
if(currentRow + 1 <= LAST_MAZE_HEIGHT_INDEX){
Maze[currentRow + 1][currentCol].SWall = PRESENT;
}
}
else if(direction == SOUTH && thereIsWall()){
Maze[currentRow][currentCol].SWall = PRESENT;
if(currentRow - 1 >= 0){
Maze[currentRow - 1][currentCol].NWall = PRESENT;
}
}
else if(direction == EAST && thereIsWall()){
Maze[currentRow][currentCol].EWall = PRESENT;
if(currentCol + 1 <= LAST_MAZE_WIDTH_INDEX){
```

```
Maze[currentRow][currentCol + 1].WWall = PRESENT;
}
}
else if(direction == WEST && thereIsWall()){
Maze[currentRow][currentCol].WWall = PRESENT;
if(currentCol - 1 >= 0){
Maze[currentRow][currentCol - 1].EWall = PRESENT;
}
}

else if(direction == NORTH && !thereIsWall()){
Maze[currentRow][currentCol].NWall = false;
if(currentRow + 1 <= LAST_MAZE_HEIGHT_INDEX){
Maze[currentRow + 1][currentCol].SWall = false;
}
}
else if(direction == SOUTH && !thereIsWall()){
Maze[currentRow][currentCol].SWall = false;
if(currentRow - 1 >= 0){
Maze[currentRow - 1][currentCol].NWall = false;
}
}
else if(direction == EAST && !thereIsWall()){
Maze[currentRow][currentCol].EWall = false;
if(currentCol + 1 <= LAST_MAZE_WIDTH_INDEX){
Maze[currentRow][currentCol + 1].WWall = false;
}
}
else if(direction == WEST && !thereIsWall()){
Maze[currentRow][currentCol].WWall = false;
if(currentCol - 1 >= 0){
Maze[currentRow][currentCol - 1].EWall = false;
}
}
}

// Checking order, North(0), East(1), West(3) then South(2)
// right, north, left, back
int MovementWithSensor(int direction){

int enteringDirectionWall = thereIsWall();
writeWall(direction);
reAdjustWayBack(direction);

// turn to check if wall is right
if(isThereWallInDir(findRight(direction)) == UNKNOWN || isThereWallInDir(findRight(direction)) ==
direction = Turn90CW(direction);
writeWall(direction);

// go right if no wall right
if(!thereIsWall()){
```

```
goFwdCell(direction);
return direction;
}
else{
direction = Turn90CCW(direction);
reAdjustWayBack(direction);
}
}

if(!enteringDirectionWall){
goFwdCell(direction);
return direction;
}

// At this point, we know there r walls on the R and N
// We are facing N

// if we know there is wall left, go thru back
if(isThereWallInDir(findLeft(direction)) == UNKNOWN || isThereWallInDir(findLeft(direction)) == NO
direction = Turn90CCW(direction);
writeWall(direction);

if(!thereIsWall()){
goFwdCell(direction);
return direction;
}
else{
reAdjustWayBack(direction);
direction = Turn90CCW(direction);
goFwdCell(direction);
return direction;
}

}
else{
reAdjustWayBack(direction);
direction = Turn90CCW(direction);
direction = Turn90CCW(direction);
goFwdCell(direction);
return direction;
}

sleep(1000000);
}
```

```
void reAdjustCCW(int direction){

direction = Turn90CCW(direction);

motor[rightDrive] = FORWARD;
motor[leftDrive] = FORWARD;
sleep(MILLISECS_TO_DRIVE_INTO_WALL);

setMotorSyncEncoder(leftDrive, rightDrive, 0, ((SIZE_OF_ONE_CELL / CIRCUMFERENCE_OF_WHEEL)*DRIVE_G

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}

Turn90CW(direction);

motor[rightDrive] = FORWARD;
motor[leftDrive] = FORWARD;
sleep(MILLISECS_TO_DRIVE_INTO_WALL);

setMotorSyncEncoder(leftDrive, rightDrive, 0, ((SIZE_OF_ONE_CELL / CIRCUMFERENCE_OF_WHEEL)*DRIVE_G

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}

timesForwardWithoutReadjust = 0;


}

void reAdjustCW(int direction){


direction = Turn90CW(direction);

motor[rightDrive] = FORWARD;
motor[leftDrive] = FORWARD;
sleep(MILLISECS_TO_DRIVE_INTO_WALL);

setMotorSyncEncoder(leftDrive, rightDrive, 0, ((SIZE_OF_ONE_CELL / CIRCUMFERENCE_OF_WHEEL)*DRIVE_G

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}

Turn90CCW(direction);

motor[rightDrive] = FORWARD;
motor[leftDrive] = FORWARD;
sleep(MILLISECS_TO_DRIVE_INTO_WALL);
```

```
setMotorSyncEncoder(leftDrive, rightDrive, 0, ((SIZE_OF_ONE_CELL / CIRCUMFERENCE_OF_WHEEL)*DRIVE_G

repeatUntil(!getMotorRunning(leftDrive) && !getMotorRunning(rightDrive)){

}
timesForwardWithoutReadjust = 0;
}

void reAdjustWayBack(int direction){
int enteringWall = thereIsWall();

if(timesForwardWithoutReadjust >=  CELLS_TO_READJUST_AFTER){
if(isThereWallInDir(findLeft(direction)) == PRESENT && enteringWall){
reAdjustCCW(direction);
}
else if(isThereWallInDir(findLeft(direction)) == PRESENT && isThereWallInDir(findBackDir(direction
direction = Turn90CCW(direction);
reAdjustCCW(direction);
direction = Turn90CW(direction);
}
else if(enteringWall && isThereWallInDir(findRight(direction)) == PRESENT){
reAdjustCW(direction);
}
else if(isThereWallInDir(findRight(direction)) == PRESENT && isThereWallInDir(findBackDir(directio
direction = Turn90CW(direction);
reAdjustCW(direction);
direction = Turn90CCW(direction);
}
}



}

int findBackDir (int currentDirection){
if(currentDirection == NORTH){
return SOUTH;
}
else if(currentDirection == EAST){
return WEST;
}
else if(currentDirection == WEST){
return EAST;
}

return NORTH;


}

int findRight(int currentDirection){
```

```
if(currentDirection == WEST){
return NORTH;
}
else{
return currentDirection + 1;
}

}

int findLeft(int currentDirection){

if(currentDirection == NORTH){
return WEST;
}
else{
return currentDirection - 1;
}

}

int isThereWallInDir(int wallDir){
if(wallDir == NORTH && Maze[currentRow][currentCol].NWall == PRESENT){
return PRESENT;
}
else if(wallDir == SOUTH && Maze[currentRow][currentCol].SWall == PRESENT){
return PRESENT;
}
else if(wallDir == EAST && Maze[currentRow][currentCol].EWall == PRESENT){
return PRESENT;
}
else if(wallDir == WEST && Maze[currentRow][currentCol].WWall == PRESENT){
return PRESENT;
}

if(wallDir == NORTH && Maze[currentRow][currentCol].NWall == UNKNOWN){
return UNKNOWN;
}
else if(wallDir == SOUTH && Maze[currentRow][currentCol].SWall == UNKNOWN){
return UNKNOWN;
}
else if(wallDir == EAST && Maze[currentRow][currentCol].EWall == UNKNOWN){
return UNKNOWN;
}
else if(wallDir == WEST && Maze[currentRow][currentCol].WWall == UNKNOWN){
return UNKNOWN;
}
return NOT_PRESENT;
}
```