I Robot Hill Climb in C

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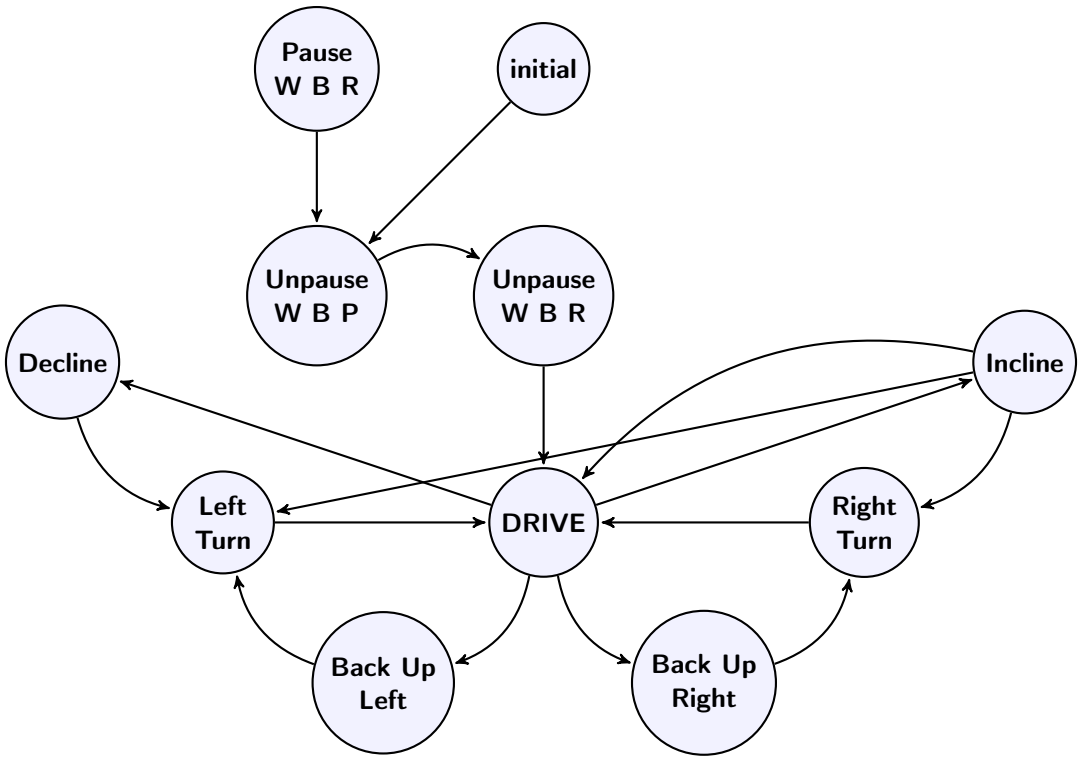
Abstract

This lab builds on programming cyber-physical systems, specifically feedback-control. Using Microsoft Visual Studio Express, we implemented a state machine in C that instructs the iRobot Create to navigate to the top of an incline while avoiding cliffs and obstacles in a simulated environment. Then using C & C++ Development Tools for NI Linux Real-Time, Eclipse Edition, we implemented a state machine in C on myRIO that instructs the iRobot Create to navigate to the top of an incline while avoiding cliffs and obstacles in a real physical environment.



I. Hill Climb in Simulation

For the hill climb simulation we programmed the virtual robot in Microsoft Visual Studio 2013a. It was in the simulator that we designed the states for the robot to follow. The states can be seen in the image above. I did however exclude the logic and paths to the pause state for readability.

The code for the hill climb was broken down into a few separate areas: an area for declarations, an area for calculations and resets, an area for pause state transitions, an area for run state transitions, and an area for state actions. Most of the logic we programmed was in the drive state. This allowed us to program for cliffs and obstacles and to transition from drive when such things were encountered and to transition back to drive so that the robot would be ready when such conditions occurred again.

```
case DRIVE:
        if (downclineState && abs(accel.y) ≤ 0.08 && abs(accel.z) ≥ 0.99 && abs(accel.x) ≤ 0.08 ...
            && (abs(netDistance − distanceAtDownclineStart) ≥ downclineDistanceThreshold)) {
            state = UNPAUSE_WAIT_BUTTON_PRESS;
        } else if (sensors.cliffFrontLeft || sensors.cliffFrontRight) {
            //state = DOWNCLINE;
            state = BACKUP_RIGHT;
            downclineState = true;
            distanceAtDownclineStart = netDistance;
        } else if (sensors.cliffLeft) {
            turnAmount = 25;
            state = RIGHT_TURN;
        } else if (sensors.cliffRight) {
            turnAmount = 25;
            state = LEFT_TURN;
        } else if (((((accel.x > xAccelInclineThreshold || accel.x < −xAccelInclineThreshold) || ...
            (accel.y > yAccelInclineThreshold || accel.y < −yAccelInclineThreshold) ) && accel.z ...
            < zAccelInclineThreshold ) && !first_incline_set) && ...
            !(sensors.bumps_wheelDrops.bumpLeft || sensors.bumps_wheelDrops.bumpRight || ...
            downclineState)) {
            state = UPINCLINE;
        } else if (sensors.bumps_wheelDrops.bumpLeft) {
            state = BACKUP_RIGHT;
            turnAmount = bumpTurnAmount;
            distanceAtManeuverStart = netDistance;
        } else if (sensors.bumps_wheelDrops.bumpRight) {
            state = BACKUP_LEFT;
            turnAmount = bumpTurnAmount;
            distanceAtManeuverStart = netDistance;
        } else {
            if (((netAngle − desiredAngle) < −5) && (abs(netDistance − distanceAtManeuverStart) ≥ ...
                150)){
                state = LEFT_TURN;
                turnAmount = abs(netAngle − desiredAngle);
            }
            if (((netAngle − desiredAngle) > 5) && (abs(netDistance − distanceAtManeuverStart) ≥ ...
                150)){
                state = RIGHT_TURN;
                turnAmount = abs(netAngle − desiredAngle);
            }
        }
```

We used feedback from the accelerometer to differentiate between states like drive and incline. We decided to go for the simple approach and try isolating values for the x, y, z accelerometers to determine if the iRobot was on an incline. We found for the simulation this worked rather well with certain thresholds set.

```
static double zAccelInclineThreshold = 1;
static double yAccelInclineThreshold = 0.1;
static double xAccelInclineThreshold = 0.1;
```

Now then that we knew we were on an incline, we needed to adjust to point directly up the incline. To do this we first we stopped our forward motion to get a more accurate reading on the accelerometers. Then we wanted to detect if we're pointing upward or downward on the incline. If we're pointing downward, first thing we do is turn around 180 degrees to point up the incline. The state then will loop and we then set the initial incline y accelerometer reading. We then turn either right or left depending on if the original incline by 3 degrees at a time, until it reaches the opposite sign. This then we set for our desired angle and we transition to the drive state. From there, if we continue to be on an incline, we recheck our incline every 500mm. We decided to use a low pass averaging filter. However we felt it was unecessary as this part of our algorithm seemed to be working pretty robustly before we introduced the filtering.

```
// lets filter the accelerometer
    medianX = (1 - FILTER_WEIGHT) * medianX + (FILTER_WEIGHT) * accel.x;
    medianY = (1 - FILTER_WEIGHT) * medianY + (FILTER_WEIGHT) * accel.y;
    medianZ = (1 - FILTER_WEIGHT) * medianZ + (FILTER_WEIGHT) * accel.z;
```

```
case UPINCLINE:
        if (accel.x < -0.15) {
            desiredAngle = netAngle + 180;
            turnAmount = 180;
            state = RIGHT_TURN;
        } else if (incline_start_angle < 0 && accel.y < 0) {
            turnAmount = 1;
            state = RIGHT_TURN;
        } else if ((incline_start_angle > 0 && accel.y > 0)) {
            turnAmount = 1;
            state = LEFT_TURN;
        } else {
            first_incline_set = true;
            desiredAngle = netAngle;
            state = DRIVE;
        }
```

Initial testing on CyberSim allowed us to catch many errors quickly and to calibrate many of our thresholds, especially those for detecting inclines. We chose to keep multiple drive speeds, faster for flat, slower for incline, as this allowed us to pass the CyberSim simulations consistently. Going slower on inclines allowed in the simulation for more accurate accelerometer readings and also kept us from going over the edge.

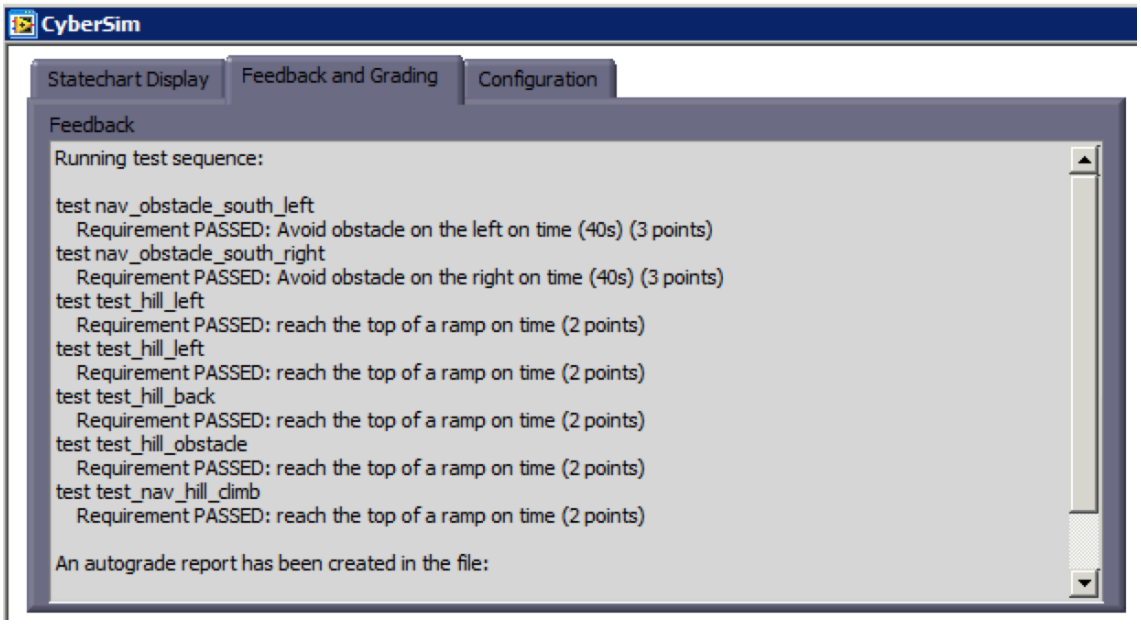


Figure 1: myRIO Board Connected to Speaker

II. Hill Climb on iRobot

We found right away that the simulator was quite different from the real world implementation. When we first uploaded our code the the iRobot, it ran in circles. We found out that (some) of the iRobots have the wheels wired opposite. So when you tell the machine to turn right, it turns left and vice versa. So we reversed the wheel direction

in our code. Then to trouble shoot we decided to log the states into a file on the iRobot. To do that we used the code below. This allowed us to diagnose and troubleshoot the issues we had with the machine much more efficently and accurately.

```
FILE *fp = fopen("statehistory.txt", "a");
fprintf(fp, "instrument readings");
fclose (fp);
```

One of the issues we had with the physical machine was that its accelerometer readings were much more sporadic. This led us to adjusting the thresholds for the accelerometer for the incline settings for better performance. I also tried making a queue of accelerometer measurements and taking a median of the values to throw away outliers. This however, while great in principal, didn't seem to work on the machine, as it slowed the acquisition of the incline state down a bit. Perhaps this would be a good technique to retry in the future when there is more time to test.

```
static double zAccelInclineThreshold = 0.97;
static double yAccelInclineThreshold = 0.14;
static double xAccelInclineThreshold = 0.14;
```

We also had to increase the incline drive speed, as the iRobot would often get stuck at the beginning of the ramp incline. With those set, then we had to adjust the settings for when we detect the cliff at the end, so the iRobot would reverse for a short distance, or we found that it would often drop a wheel off the side while turning around. We found that we had to include some "corrections" in our code for the physical iRobot in comparision to the simulation. For example we uncorrected an over correction for the angle up an incline. And we also had to adjust from turning around 180 degrees to 170 degrees as we found that is what actually turned the machine around for reverse downward the ramp.

```
  else if (inclineCorrection){
              inclineCorrection = false;
              turnAmount = 5;
              if (incline_start_angle < 0) {
                  state = LEFT_TURN;
              }
              else {
                  state = RIGHT_TURN;
              }
          }
```

III. Feedback

We found this lab to be a lot of work. We spent not only our lab time, but much of Friday, Saturday, Monday, and Wednesday on this lab to get everything correct. One thing we learned is to try and find a good trouble shooting tool. This for us on this project was logging states and sensor readings on the iRobot. Beyond that, I would recommend in the future that maybe this lab be paced out to be over two weeks. I think this would relieve much of the pressure on students, and would allow more time for experimentation with the iRobot. I have a few ideas that I believe would lead to a better implementation but unfortunately don't have the time to try them out. And it's the trying it out that in the end leads to learning.

irobotNavigationStatechart.c

```
#include "irobotNavigationStatechart.h"
#include <math.h>
#include <stdlib.h>
#include <stdio.h>

/// Program States
typedef enum{
    INITIAL = 0,                        ///< Initial state
    PAUSE_WAIT_BUTTON_RELEASE,          ///< Paused; pause button pressed down, wait until ...
        released before detecting next press
    UNPAUSE_WAIT_BUTTON_PRESS,          ///< Paused; wait for pause button to be pressed
    UNPAUSE_WAIT_BUTTON_RELEASE,        ///< Paused; pause button pressed down, wait until ...
        released before returning to previous state
    DRIVE,                              ///< Drive straight
    TURN,                               ///< Turn
    RIGHT_TURN,                         ///< Turn right
    LEFT_TURN,                          ///< Turn left
    BACKUP_RIGHT,                       ///< Backup followed by a right
    BACKUP_LEFT,                        ///< Backup followed by a left
    INCLINE,                            ///< Sets variables to go up hill
    DECLINE                             ///< Begin the process going down the hill
} robotState_t;


#define DEG_PER_RAD            (180.0 / M_PI)        ///< degrees per radian
#define RAD_PER_DEG            (M_PI / 180.0)        ///< radians per degree
#define ANGLE_TOLERANCE           (0.01)                // What we can hope is a safe tolerance ...
    when dealing with the angle measured by the robot

extern FILE *fp;                        ///< Pointer to statehistory text file used to log ...
    errors. Definition in target/myrio/main.c

void irobotNavigationStatechart(
    const int32_t                   netDistance,
    const int32_t                   netAngle,
    const irobotSensorGroup6_t      sensors,
    const accelerometer_t           accel,
    const bool                      isSimulator,
    int16_t * const                 pRightWheelSpeed,
    int16_t * const                 pLeftWheelSpeed
    ){
    // local state
    static robotState_t             state = INITIAL;                    // Initial state
    static robotState_t             unpausedState = DRIVE;              // state history for ...
        pause region
    static int32_t                  distanceAtManeuverStart = 0;        // distance robot had ...
        travelled when a maneuver begins, in mm
    static int32_t                  angleAtManeuverStart = 0;           // angle through which ...
        the robot had turned when a maneuver begins, in deg

    // outputs
    int16_t                         leftWheelSpeed = 0;                 // speed of the left ...
        wheel, in mm/s
    int16_t                         rightWheelSpeed = 0;                // speed of the right ...
        wheel, in mm/s

    //*****************************************************
    // state data - process inputs                         *
    //*****************************************************
    static int32_t turnAmount;
    static bool first_incline;
    static bool declineState;
    //static bool second_incline;
```

```
55      static double incline_start_angle;                                  // y.accel at which we ...
            start the incline
56      static int32_t desiredAngle;                                        // trajectory we want to ...
            follow
57      static bool first_incline_set;                                      // indicate that we are ...
            on the incline
58      static int32_t driveSpeed = 200;                                    // variable holds the ...
            speed for the iRobot in drive
59      static int32_t bumpTurnAmount = 15;                                 // deg to turn the robot ...
            on a bump or a cliff
60      static int32_t turnSpeed = 50;                                      // speed to turn at
61      static int32_t backUpDistance = 20;                                 // how far to back up
62      static int32_t inclineRecalcDistance = 500;                         // after how many mm do ...
            you want to recheck trajectory
63      static int32_t distanceAtDECLINEStart;                              // distance when the edge ...
            of the cliff was seen
64      static int32_t DECLINEDistanceThreshold = 2000;                     // since there is a ...
            plateau at the top of the incline, need a thresh after which we want to stopped
65      static double zAccInclThresh = 0.96;                                // z acc thresh for ...
            incline/flat
66      static double xAccInclThresh = 0.1;                                 // x acc thresh for ...
            incline/decline/flat
67      static double yAccInclThresh = 0.1;                                 // y acc thresh for ...
            incline/decline/flat
68
69      // Let's reset incline values after a certain distance so it can recalc or do multiple inclines
70      if ((abs(netDistance - distanceAtManeuverStart) >= inclineRecalcDistance)) {
71          first_incline = false;
72          first_incline_set = false;
73          distanceAtManeuverStart = netDistance;
74          driveSpeed = 200;
75      }
76
77
78      //*****************************************************
79      // state transition - pause region (highest priority) *
80      //*****************************************************
81      if (state == INITIAL
82          || state == PAUSE_WAIT_BUTTON_RELEASE
83          || state == UNPAUSE_WAIT_BUTTON_PRESS
84          || state == UNPAUSE_WAIT_BUTTON_RELEASE
85          || sensors.buttons.play                 // pause button
86          ){
87          switch (state){
88          case INITIAL:
89              // set state data that may change between simulation and real-world
90              if (isSimulator){
91              }
92              else{
93              }
94              state = UNPAUSE_WAIT_BUTTON_PRESS; // place into pause state
95              break;
96          case PAUSE_WAIT_BUTTON_RELEASE:
97              // remain in this state until released before detecting next press
98              if (!sensors.buttons.play){
99                  state = UNPAUSE_WAIT_BUTTON_PRESS;
100             }
101             break;
102         case UNPAUSE_WAIT_BUTTON_RELEASE:
103             // user pressed 'pause' button to return to previous state
104             if (!sensors.buttons.play){
105                 state = unpausedState;
106             }
107             break;
108         case UNPAUSE_WAIT_BUTTON_PRESS:
```

```
109             // remain in this state until user presses 'pause' button
110             if (sensors.buttons.play){
111                 state = UNPAUSE_WAIT_BUTTON_RELEASE;
112             }
113             break;
114         default:
115             // must be in run region, and pause button has been pressed
116             unpausedState = state;
117             state = PAUSE_WAIT_BUTTON_RELEASE;
118             break;
119         }
120     }
121 
122     /*****************************************************
123      * THIS SWITCH STATEMENT HANDLES STATE TRANSITIONS   *
124      *****************************************************/
125     switch (state) {
126 
127     /* Drive is the main state in which the robot runs. This state needs to be sensitive to a ...
            variety of events
128      * 1. THE END OF THE CHALLENGE (Stop)
129      * 2. THE CLIFF AT THE TOP OF THE INCLINE (Detect, Backup, and Turn 180)
130      * 3. THE EDGES OF THE INCLINE (Avoid like you would a bump)
131      * 4. THE INCLINE ITSELF (Go directly up it)
132      * 5. OBSTACLES (Avoid the obstacle and then follow original course)
133      *
134      */
135     case DRIVE:
136     // This part of DRIVE handles the end of the challenge — we are on the decline, and the x ...
            acceleration and z acceleration indicates we are on flat
137     // ground. Also, the distance driven away from the cliff (and off the plateau) needs to have ...
            crossed a threshold.
138         if (declineState && abs(medianY) ≤ 0.08 && abs(medianZ) ≥ 0.99 && abs(medianX) ≤ 0.08 && ...
                (abs(netDistance − distanceAtDownclineStart) ≥ downclineDistanceThreshold)) {
139             state = UNPAUSE_WAIT_BUTTON_PRESS;
140             fprintf(fp, "state: 1 UNPAUSE_WAIT_BUTTON_PRESS, accel.x: %+1.3f, accel.y: %+1.3f, ...
                    accel.z: %+1.3f      leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, ...
                    frontLeftCliff: %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
141         }
142         // the front cliff sensors indicate the cliff at the top of the hill
143         else if ((sensors.cliffFrontLeft || sensors.cliffFrontRight) && !declineState && ...
                !onIncline) {
144             state = DECLINE;
145             declineState = true;
146             distanceAtDownclineStart = netDistance;
147             fprintf(fp, "state: 2 DECLINE, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: %+1.3f      ...
                    leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, frontLeftCliff: %d, ...
                    frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
148 
149         }
150         // The edge of incline is detected — treat this like a bump
151         else if (sensors.cliffLeft) {
152             turnAmount = 25;
153             state = RIGHT_TURN;
154             fprintf(fp, "state: 3 RIGHT_TURN, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: %+1.3f ...
                        leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, frontLeftCliff: ...
                    %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
```

```
                sensors.cliffFrontRight);
155
156         }
157         // Edge of the incline detected - treat as a bump
158         else if (sensors.cliffRight) {
159             turnAmount = 25;
160             state = LEFT_TURN;
161             fprintf(fp, "state: 4 LEFT_TURN, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: %+1.3f ...
                        leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, frontLeftCliff: ...
                    %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
162
163         }
164         // If we detect that we are on the incline, set to the INCLINE state
165         else if ((onIncline && !first_incline_set) && !(sensors.bumps_wheelDrops.bumpLeft || ...
                sensors.bumps_wheelDrops.bumpRight || declineState)) {
166             state = INCLINE;
167             fprintf(fp, "state: 5 INCLINE, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: %+1.3f      ...
                    leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, frontLeftCliff: %d, ...
                    frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
168         }
169         // obstacle detected onthe left - backup and turn right
170         else if (sensors.bumps_wheelDrops.bumpLeft) {
171             state = BACKUP_RIGHT;
172             turnAmount = bumpTurnAmount;
173             distanceAtManeuverStart = netDistance;
174             fprintf(fp, "state: 6 BACKUP_RIGHT, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: %+1.3f ...
                        leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, frontLeftCliff: ...
                    %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
175         }
176         // obstacle on right - backup and turn left
177         else if (sensors.bumps_wheelDrops.bumpRight) {
178             state = BACKUP_LEFT;
179             turnAmount = bumpTurnAmount;
180             distanceAtManeuverStart = netDistance;
181             fprintf(fp, "state: 7 BACKUP_LEFT, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: %+1.3f ...
                        leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, frontLeftCliff: ...
                    %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
182         }
183         // Nothing detected - make sure that we are heading in the desiredAngle orientation
184         else {
185             if (((netAngle - desiredAngle) < -5) && (abs(netDistance - distanceAtManeuverStart) ≥ ...
                    150)){
186                 state = LEFT_TURN;
187                 turnAmount = abs(netAngle - desiredAngle);
188                 fprintf(fp, "state: 8 LEFT_TURN, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: ...
                        %+1.3f      leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, ...
                        frontLeftCliff: %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                        sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                        sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                        sensors.cliffFrontRight);
189
190             }
191             if (((netAngle - desiredAngle) > 5) && (abs(netDistance - distanceAtManeuverStart) ≥ ...
```

```
                150)){
192             state = RIGHT_TURN;
193             turnAmount = abs(netAngle - desiredAngle);
194             fprintf(fp, "state: 9 RIGHT_TURN, accel.x: %+1.3f, accel.y: %+1.3f, accel.z: ...
                    %+1.3f      leftBump: %d, rightBump: %d, leftCliff: %d, rightCliff: %d, ...
                    frontLeftCliff: %d, frontRightCliff: %d \n", accel.x, accel.y, accel.z, ...
                    sensors.bumps_wheelDrops.bumpLeft, sensors.bumps_wheelDrops.bumpRight, ...
                    sensors.cliffLeft, sensors.cliffRight, sensors.cliffFrontLeft, ...
                    sensors.cliffFrontRight);
195
196         }
197     }
198
199     break;
200 // In case we are turning, turn only when we have turned the angle we want to
201 case RIGHT_TURN:
202 case LEFT_TURN:
203     if (abs(netAngle - angleAtManeuverStart) >= turnAmount) {
204         angleAtManeuverStart = netAngle;
205         distanceAtManeuverStart = netDistance;
206         state = DRIVE;
207     }
208     break;
209 // backup the backup distance, then go to the LEFT_TURN state
210 case BACKUP_LEFT:
211     if ((abs(netDistance - distanceAtManeuverStart) >= backUpDistance)) {
212         angleAtManeuverStart = netAngle;
213         distanceAtManeuverStart = netDistance;
214         state = LEFT_TURN;
215     }
216     break;
217 // backup the backup distance and then go to RIGHT_TURN state
218 case BACKUP_RIGHT:
219     if ((abs(netDistance - distanceAtManeuverStart) >= backUpDistance)) {
220         angleAtManeuverStart = netAngle;
221         distanceAtManeuverStart = netDistance;
222         state = RIGHT_TURN;
223     }
224     break;
225 // if we have detected the hill, make sure that robot is going straight up the hill by ...
        ensuring accel.y is 0
226 case INCLINE:
227     // This clause ensures that if placed facing down the incline, we go up it before going down
228     if (medianX < -0.15) {
229         desiredAngle = netAngle + 180;
230         turnAmount = 180;
231         state = RIGHT_TURN;
232     }
233     else if (incline_start_angle < 0 && medianY < 0) {
234         turnAmount = 2;
235         state = RIGHT_TURN;
236         inclineCorrection = true;
237     }
238     else if ((incline_start_angle > 0 && medianY > 0)) {
239         turnAmount = 2;
240         state = LEFT_TURN;
241         inclineCorrection = true;
242     }
243     // Empirical section to compensate for real world weirdness. This helps the lil robot to ...
            straight up the hill
244     else if (inclineCorrection){
245         inclineCorrection = false;
246         turnAmount = 5;
247         if (incline_start_angle < 0) {
248             state = LEFT_TURN;
```

```
            }
            else {
                state = RIGHT_TURN;
            }
        }
        // Things are good. Go to drive
        else {
            first_incline_set = true;
            desiredAngle = netAngle;
            state = DRIVE;
        }
        break;
    // The end is near!! Back up by 4cm and then turn 180 deg (170 in code gives us 180 in real life)
    case DECLINE:
        if ((abs(netDistance - distanceAtManeuverStart) >= 40)) {
            desiredAngle += 170;
            turnAmount = 170;
            state = LEFT_TURN;
        }
        break;
    default:
        break;
    }


    //*****************
    //* state actions *
    //*****************
    switch (state){
    case INITIAL:
    case PAUSE_WAIT_BUTTON_RELEASE:
    case UNPAUSE_WAIT_BUTTON_PRESS:
    case UNPAUSE_WAIT_BUTTON_RELEASE:
        // in pause mode, robot should be stopped
        leftWheelSpeed = rightWheelSpeed = 0;
        break;

    case DRIVE:
        // full speed ahead!
        leftWheelSpeed = rightWheelSpeed = driveSpeed;
        break;

    case LEFT_TURN:
        leftWheelSpeed = turnSpeed; // switched for robot
        rightWheelSpeed = -leftWheelSpeed;
        break;

    case RIGHT_TURN:
        leftWheelSpeed = -turnSpeed; // switched for robot
        rightWheelSpeed = -leftWheelSpeed;
        break;

    case TURN:
        leftWheelSpeed = turnSpeed;
        rightWheelSpeed = -leftWheelSpeed;
        break;
    // wheels turn reverse
    case BACKUP_LEFT:
    case BACKUP_RIGHT:
        leftWheelSpeed = -turnSpeed;
        rightWheelSpeed = -turnSpeed;
        break;
    // slow down, lil horsey. The incline have them monsters
    case INCLINE:
        driveSpeed = 95; // slows down after entering ramp
```

```
314             leftWheelSpeed = rightWheelSpeed = 0;
315             if (!first_incline) {
316                 incline_start_angle = medianY;
317                 first_incline = true;
318             }
319             break;
320         case DECLINE:
321             leftWheelSpeed = rightWheelSpeed = -driveSpeed;
322             break;
323         default:
324             leftWheelSpeed = rightWheelSpeed = 0;
325             break;
326         }
327
328
329         // write outputs
330         *pLeftWheelSpeed = leftWheelSpeed;
331         *pRightWheelSpeed = rightWheelSpeed;
332     }
```

statehistory.txt

```
1  state: 5 UPINCLINE, accel.x: +0.141, accel.y: −0.072, accel.z: +0.949      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
2  state: 5 UPINCLINE, accel.x: +0.179, accel.y: −0.124, accel.z: +0.961      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
3  state: 5 UPINCLINE, accel.x: +0.184, accel.y: −0.150, accel.z: +0.941      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
4  state: 5 UPINCLINE, accel.x: +0.149, accel.y: −0.129, accel.z: +0.919      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
5  state: 5 UPINCLINE, accel.x: +0.179, accel.y: −0.134, accel.z: +0.926      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
6  state: 5 UPINCLINE, accel.x: +0.173, accel.y: −0.103, accel.z: +0.959      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
7  state: 5 UPINCLINE, accel.x: +0.182, accel.y: −0.049, accel.z: +0.911      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
8  state: 5 UPINCLINE, accel.x: +0.198, accel.y: −0.069, accel.z: +0.942      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
9  state: 5 UPINCLINE, accel.x: +0.181, accel.y: −0.120, accel.z: +0.922      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
10 state: 5 UPINCLINE, accel.x: +0.223, accel.y: −0.070, accel.z: +0.914      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
11 state: 5 UPINCLINE, accel.x: +0.157, accel.y: −0.020, accel.z: +0.944      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
12 state: 5 UPINCLINE, accel.x: +0.184, accel.y: −0.055, accel.z: +0.938      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
13 state: 5 UPINCLINE, accel.x: +0.192, accel.y: −0.048, accel.z: +0.950      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
14 state: 5 UPINCLINE, accel.x: +0.162, accel.y: +0.061, accel.z: +0.950      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
15 state: 5 UPINCLINE, accel.x: +0.201, accel.y: +0.060, accel.z: +0.955      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
16 state: 5 UPINCLINE, accel.x: +0.202, accel.y: +0.001, accel.z: +0.968      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
17 state: 6 BACKUP_RIGHT, accel.x: +0.120, accel.y: −0.010, accel.z: +0.987      leftBump: 1, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
18 state: 5 UPINCLINE, accel.x: +0.153, accel.y: +0.044, accel.z: +0.942      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
19 state: 5 UPINCLINE, accel.x: +0.125, accel.y: +0.161, accel.z: +0.950      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
20 state: 5 UPINCLINE, accel.x: +0.179, accel.y: +0.189, accel.z: +0.943      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
21 state: 5 UPINCLINE, accel.x: +0.185, accel.y: +0.251, accel.z: +0.924      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
22 state: 5 UPINCLINE, accel.x: +0.139, accel.y: +0.193, accel.z: +0.949      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
23 state: 5 UPINCLINE, accel.x: +0.174, accel.y: +0.173, accel.z: +0.956      leftBump: 0, ...
       rightBump: 0, leftCliff: 0, rightCliff: 0, frontLeftCliff: 0, frontRightCliff: 0
```