CS684 :: Lab 2: Heptagon code for Line following

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YouTube Demo link

- YouTube Link

Overview

This document explains the implementation of a PID-based line-following robot in Heptagon. The robot uses five white-line sensors to detect a black line on a white surface and adjusts its motor velocities accordingly to stay on track.

Inputs and Outputs

Inputs

- Five white-line sensors (`sen0, sen1, sen2, sen3, sen4`), each providing values between `0-1023`.
- Lower values indicate a white surface, and higher values indicate a black surface.

Outputs

- `v_l`: Velocity of the left motor (`0-100`).
- `v_r`: Velocity of the right motor (`0-100`).
- `dir`: Robot movement direction:
  - `0` - Stop
  - `1` - Forward
  - `2` - Left
  - `3` - Right
  - `4` - Backward

Scenarios Considered

- **straight** line => **neutral** (left and right motor velocity @50)
  - if reading **straight is continued** for some cycles => **accelerate** (increase both motor velocity by 5)
- different types of turns in both left and right direction. [+- means one motor velocity is increased while the other is decreased based on direction]
  1. **Minor Turn**: Less than 45° => **velocity +- ~10**
  2. **Angled Turn**: 45° to 90° => **velocity +- ~25**
  3. **Sharp Turn**: 90°-135° => **velocity +- ~35**

    4. **U Turn**: More than 135°-180° => **velocity +- ~50**
- robot **losing the track** => **backward**
- robot reaching the **finish line** (all black strip) => **stop**

Assumptions

- The robot is moving on a **well-defined black track on a white surface**.
- Sensors provide reliable values between `0-1023`.
- If the sensor is on **white** surface, it gives reading in range **[0, 100]**.
- If the sensor is on **black** surface, it gives reading in range **[800, 1023]**.
- The **black line width is 2cm**.
- There is a **finish line** which is all black strip ie. all sensors reads high value.
- Some random **`kp = 0.06`** has been selected as proportional gain that balances responsiveness without excessive oscillations.
- **`kd` and `ki`**: Set to zero initially;
- **(kp, kd, ki)** will be tuned empirically for optimal stability and steady-state performance.
- Motor velocities are in the range `0-100`.
- The weight distribution for sensors is symmetrical around the center.

Implementation Details

PID Controller with direct sensor values has been used.

1. First weighted average of the 5 sensor values is calculated.
2. Then, PID Error is calculated on this Weighted Average Value.
3. Based on the PID error direction is determined and motor velocity is updated.

Following are the details.

1. Weighted Average of five Sensors

The five sensor values are processed to compute the weighted avg of readings. The `sensor_avg` calculation formula is: $$ sensor\_avg = \frac{\sum (sensor_i \times weight_i)}{\sum sensor_i} $$

Weights:

- weights chosen: **[-1000, -500, 0, 500, 1000]**
- The **middle sensor's weight is zero** because it should contribute no error when perfectly aligned.
- **Negative weights** for left-side sensors represent deviations to the **left**.
- **Positive weights** for right-side sensors represent deviations to the **right**.
- If error is negative take left else if positive take right.
- To simulate floating operations, large weights (e.g. 10 has been taken as 10000) have been chosen to give sufficient resolution in integer operations.

2. PID Error Calculation

In ideal condition only the middle sensor would be on black so `ideal_value` would be 0. $$ error = sensor\_avg - ideal\_value = sensor\_avg $$ So, The PID error is computed on `sensor_avg` using proportional, integral, and derivative components:

```
node calPidError(value: int) returns (pid_error: int)
var p, i, d: int;
let
     p = value;
     (* Integral term with overflow prevention *)
     i = if ((0->pre(i) + value) <= max_i)
            then (0->pre(i) + value)
         else
            max_i;
     d = value - 0->pre(value);
     pid_error = (kp*p + ki*i + kd*d) / kscale;
tel
```

- Here, we use Kscale to approximate floating-point division using integer arithmetic.
- **`max_i = 200,000,000`**: Limits the integral term to prevent overflow during long-term accumulation.

3. Direction and motor velocity update

a. Determining Direction

```
     if sensor_sum > (black_thresh*5) then 0  -- all black -> stop
else if sensor_sum < (white_thresh*5) then 4  -- all white -> backward
else if pid_error = 0 then 1  -- no error -> move forward
else if sensor_avg < 0 then 2  -- Negative error -> turn left
else if sensor_avg > 0 then 3  -- Positive error -> turn right
else 0; -- fallback/default
```

b. Adjusting Motor velocities

Adjusting motor velocities based on pid_error while ensuring they remain within the [0,100] range.

In straight line

```
v_l = 50 -> safe_motor_update(pre(v_l), 5);
v_r = 50 -> safe_motor_update(pre(v_r), 5);
```

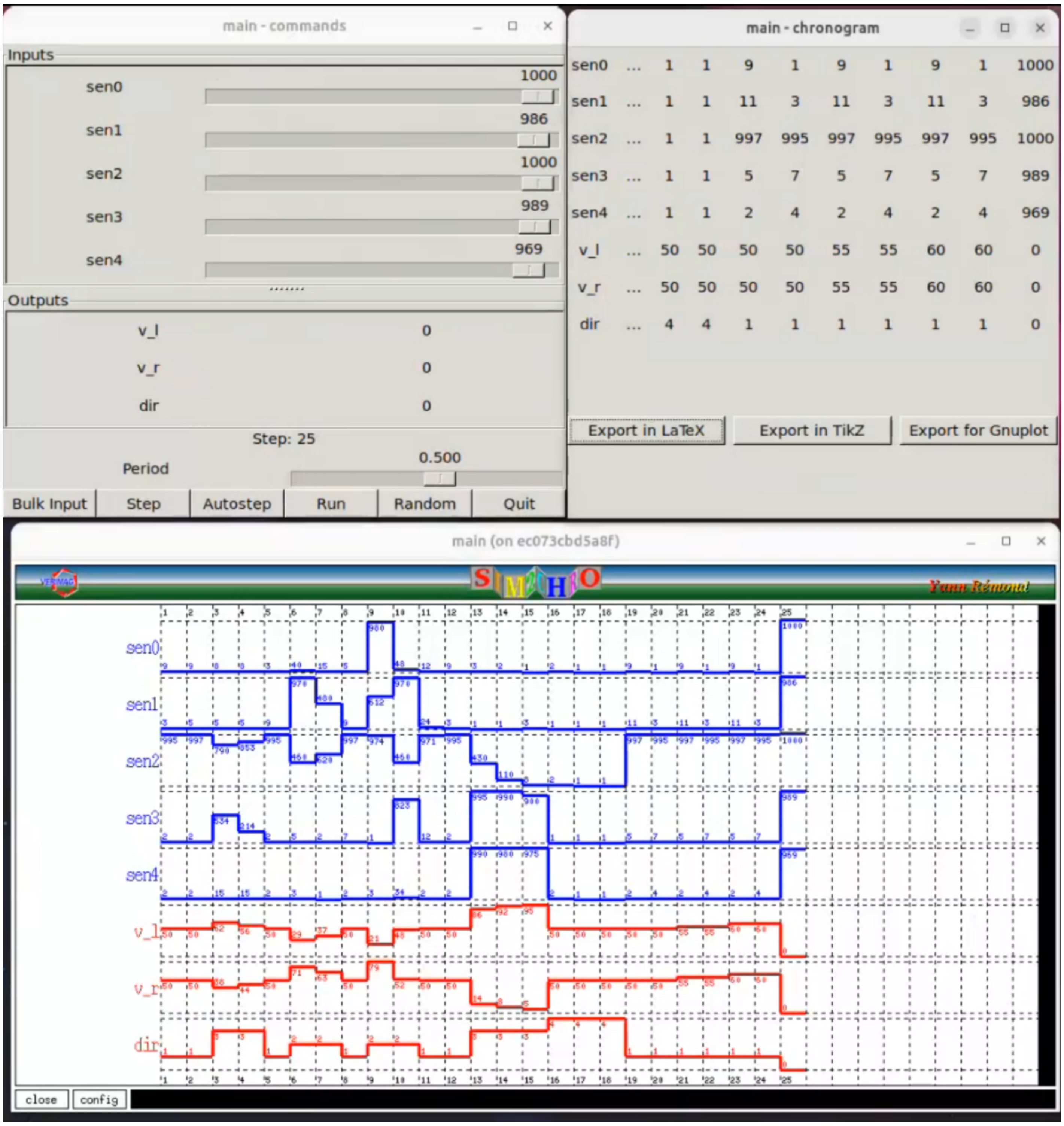
During turn: pid_error would be negative for left turn and positive for right turn.

```
v_l = safe_motor_update(50, pid_error);
v_r = safe_motor_update(50, -1*pid_error);
```

Simulation Conditions and Outputs

- YouTube Link

Screenshot



main - commands

Inputs

sen0	1000
sen1	986
sen2	1000
sen3	989
sen4	969

Outputs

v_l	0
v_r	0
dir	0

Step: 25

Period 0.500

main - chronogram

sen0	...	1	1	9	1	9	1	9	1	1000
sen1	...	1	1	11	3	11	3	11	3	986
sen2	...	1	1	997	995	997	995	997	995	1000
sen3	...	1	1	5	7	5	7	5	7	989
sen4	...	1	1	2	4	2	4	2	4	969
v_l	...	50	50	50	50	55	55	60	60	0
v_r	...	50	50	50	50	55	55	60	60	0
dir	...	4	4	1	1	1	1	1	1	0

Input/Output table

Step	sen0	sen1	sen2	sen3	sen4	v_l	v_r	dir	comment
1	9	3	995	2	2	50	50	1	straight
2	9	5	997	2	2	55	55	1	straight
3	8	5	790	534	15	64	36	3	minor right => +-10
4	8	5	853	214	15	57	43	3	minor right => +-10
5	3	9	995	2	2	50	50	1	straight
6	40	970	460	5	3	26	74	2	angled left => -+25
7	15	480	620	2	1	35	65	2	angled left => -+25
8	5	9	997	7	2	50	50	1	straight
9	980	612	974	1	3	16	84	2	sharp left => -+35
10	48	970	460	823	34	48	52	2	sharp left => -+35
11	12	24	971	12	2	49	51	2	straight
12	9	3	995	2	2	50	50	1	straight
13	3	1	430	995	990	92	8	3	U-turn right => +-50
14	2	1	110	990	980	99	1	3	U-turn right => +-50
15	1	3	8	900	975	100	0	3	U-turn right => +-50
16	2	1	2	1	2	50	50	4	outoftrack => back
17	1	1	1	1	1	50	50	4	outoftrack => back
18	1	1	1	1	1	50	50	4	outoftrack => back
19	9	11	997	5	2	50	50	1	straight
20	1	3	995	7	4	55	55	1	accelerate => ++5
21	9	11	997	5	2	60	60	1	accelerate => ++5
22	1	3	995	7	4	65	65	1	accelerate => ++5
23	9	11	997	5	2	70	70	1	accelerate => ++5
24	1	3	995	7	4	75	75	1	accelerate => ++5
25	1000	986	1000	989	969	0	0	0	finish => stop