Autonomous Robots: Assignment 2

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a)

Starting from the kinematic equations derived in the lectures

$$x_1 = x_0 + \int_{t_0}^{t_1} \frac{v_R(t) + v_L(t)}{2} \cos\phi(t)\, dt \tag{1}$$

$$y_1 = y_0 + \int_{t_0}^{t_1} \frac{v_R(t) + v_L(t)}{2} \sin\phi(t)\, dt \tag{2}$$

$$\phi_1 = \phi_0 + \int_{t_0}^{t_1} \frac{v_R(t) - v_L(t)}{2R}\, dt \tag{3}$$

Replacing $v_R = v_0 t/t_2$ and $v_L = v_0 t/t_1$ then simplifying

$$x_1 = x_0 + \int_{t_0}^{t_1} \frac{v_0 t}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \cos\phi(t)\, dt \tag{4}$$

$$y_1 = y_0 + \int_{t_0}^{t_1} \frac{v_0 t}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \sin\phi(t)\, dt \tag{5}$$

$$\phi_1 = \phi_0 + \int_{t_0}^{t_1} \frac{v_0 t}{2R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right) dt \tag{6}$$

Integrating with respect to time from the initial condition $x_0 = y_0 = \phi_0 = t_0 = 0$ to $t_1 = t$

$$x(t) = \int_0^t \frac{v_0 t}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \cos\phi(t)\, dt \tag{7}$$

$$y(t) = \int_0^t \frac{v_0 t}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \sin\phi(t)\, dt \tag{8}$$

$$\phi(t) = \int_0^t \frac{v_0 t}{2R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right) dt = \frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right) \tag{9}$$

Inserting eq. 9 into eq. 7 and 8

$$\begin{aligned} x(t) &= \int_0^t \frac{v_0 t}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \cos\left[\frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right] dt && (10) \\ &= \frac{v_0}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \frac{2R t_1 t_2}{v_0 (t_1 - t_2)} \sin\left[\frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right] && (11) \\ &= \frac{t_1 + t_2}{t_1 - t_2} R \sin\left[\frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right] && (12) \end{aligned}$$

$$\begin{aligned} y(t) &= \int_0^t \frac{v_0 t}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \sin\left[\frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right] dt && (13) \\ &= \frac{v_0}{2} \left(\frac{1}{t_2} + \frac{1}{t_1}\right) \frac{4R t_1 t_2}{v_0 (t_1 - t_2)} \left[1 - \cos\left[\frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right]\right] && (14) \\ &= \frac{t_1 + t_2}{t_1 - t_2} R \left[1 - \cos\left[\frac{v_0 t^2}{4R} \left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right]\right] && (15) \end{aligned}$$

Thus, our general equations of motion are

$$x(t) = \frac{t_1 + t_2}{t_1 - t_2} R \sin\left[\frac{v_0 t^2}{4R}\left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right] \tag{16}$$

$$y(t) = \frac{t_1 + t_2}{t_1 - t_2} R \left[1 - \cos\left[\frac{v_0 t^2}{4R}\left(\frac{1}{t_2} - \frac{1}{t_1}\right)\right]\right] \tag{17}$$

$$\phi(t) = \frac{v_0 t^2}{4R}\left(\frac{1}{t_2} - \frac{1}{t_1}\right) \tag{18}$$

Inserting $v_0 = 0.5$ m/s, $t_1 = 10$s, $t_2 = 5$s, $R = 0.12$m gives

$$x(t) = 0.36 \sin\left(\frac{5}{48} t^2\right) \tag{19}$$

$$y(t) = 0.36 \left[1 - \cos\left(\frac{5}{48} t^2\right)\right] \tag{20}$$

$$\phi(t) = \frac{5}{48} t^2 \tag{21}$$

Numerically integrating eq. 1, 2 and 3, as well as evaluating the analytical eq. 19 and 20 both give the same trajectory as in figure 1.

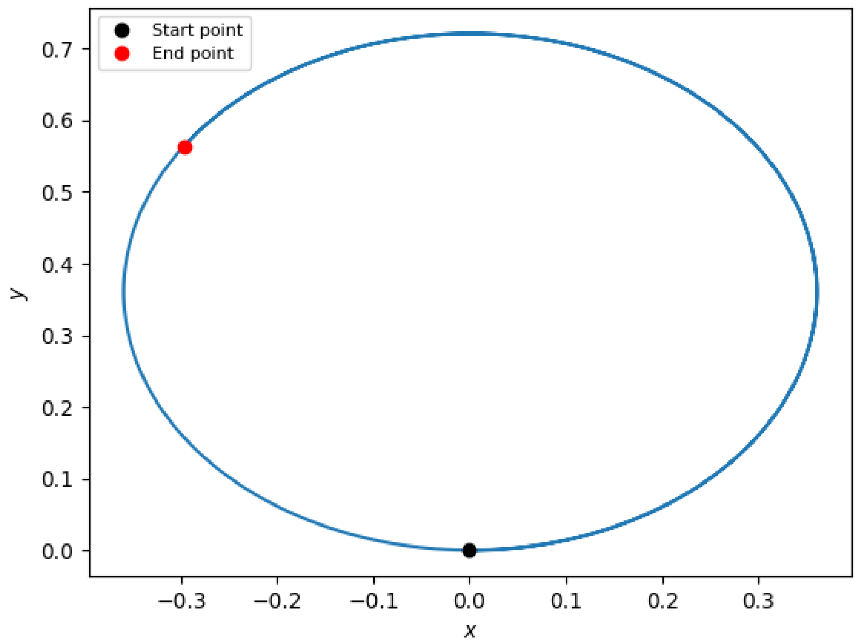

Figure 1

b)

To run the program for part b) follow the instructions below.

1. CD to `/opendlv-assignment-2/opendlv-virtual-motor-kiwi`
2. Build the dockerfile with this command:

```
docker build -t registry.opendlv.org/community/opendlv-virtual-motor-kiwi:1.0 .
```

3. CD to `/opendlv-assignment-2/opendlv-logic-test-kiwi-b`
4. Build the dockerfile with this command:

```
docker build -t registry.opendlv.org/community/opendlv-logic-test-kiwi-b:1.0 .
```

5. When done building both docker files, CD to `/opendlv-assignment-2` with two different terminals

6. Run this command in the first terminal:

```
docker compose -f interface-kiwi.yml up
```

7. Run this command in the second terminal:

```
docker compose -f simulate-kiwi-b.yml up
```

8. Point your web browser to localhost:8081

At best the car ended up at around $(x, y) = (0.2, -0.4)$ as intended. The frequencies for the microservices opendlv-virtual-motor-kiwi and opendlv-virtual-space were set to 45 where as the frequency of the opendlv-logic-test-kiwi was set to 40. This means that the time step *dt* of the numerical integration was approximately 0.02s. A plot of the frame of the taken path can be seen in fig. 2. Another plot of the path taken in euclidean space can be seen in fig. 3.

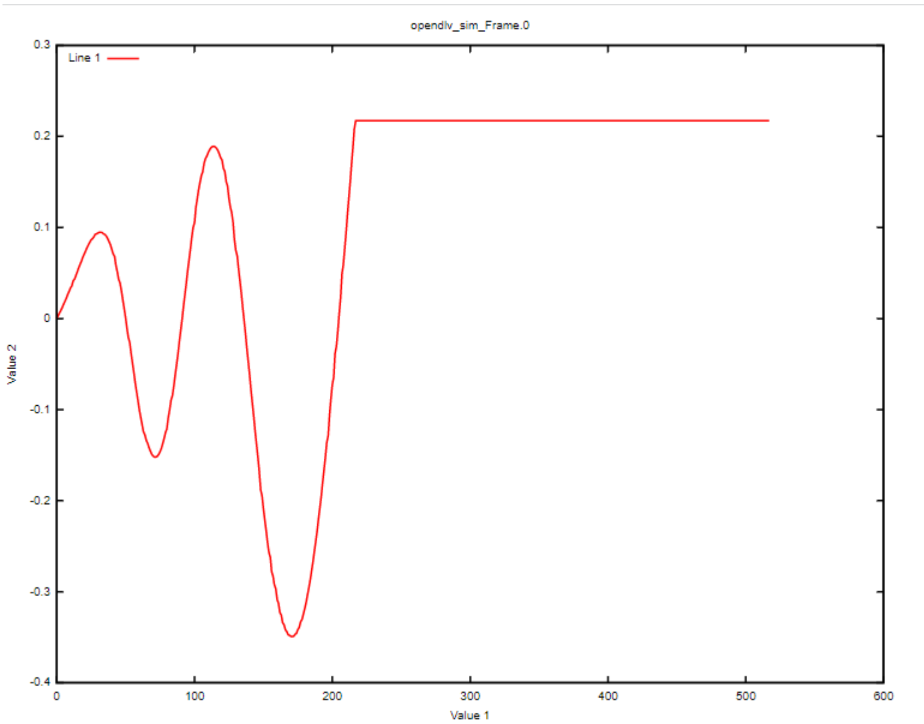

Figure 2: Frame plot of actual path taken, $dt \approx 0.02$.

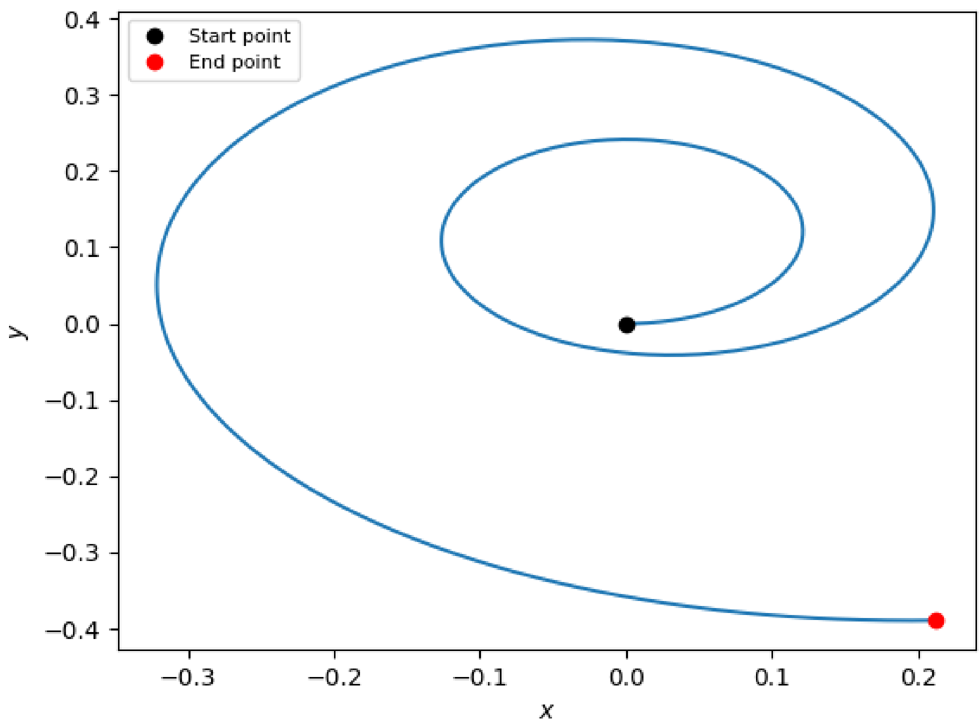

Figure 3: Path taken in euclidean space, numerically integrated in python, $dt = 0.02$.

c)

A finite state machine (FSM) was implemented to detect and avoid obstacles around the car. The FSM consisted of a behaviour that rotates the car to the left if the the distance sensors measure below a distance threshold to the right or in front. This in theory means that the car would never hit an obstacle and continuously search the environment because it would consistently turn slightly and move forward. A digram of the implemented FSM can be sin in fig. 4.

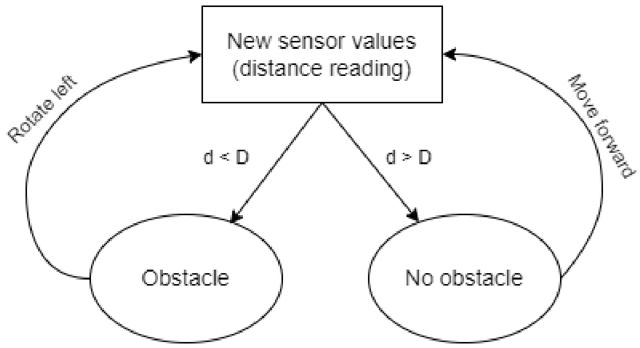

Figure 4: FSM diagram of the implemented FSM where d is the measured distances from the front and the right sensor and D is the distance threshold for what is considered for the car to face an obstacle.

To run the program for part c) follow the instructions below. Before following the instructions, make sure you are still in `/opendlv-assignment-2` and run this command:
`docker compose -f simulate-kiwi-b.yml down`

Do NOT take down the docker compose for interface.yml, leave it as it is in one terminal. Then do the following.

1. In a second terminal, CD into `/opendlv-assignment-2/opendlv-logic-test-kiwi-c`
2. Build the dockerfile with this command (note the 'c' instead of the 'b'):

```
docker build -t registry.opendlv.org/community/opendlv-logic-test-kiwi-c:1.0 .
```

3. When done building, CD into `/opendlv-assignment-2`
4. Run this command:

```
docker compose -f simulate-kiwi-c.yml up
```

8. Point your web browser to localhost:8081