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3D Graph-Based Formation Odor Source Localization

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Odor in the form of a chemical component is emitted by various sources. Some of these sources can be very dangerous and hard to localize, like for instance a gas leak, or an underground mine. Soares et al. [1, 2] developed an algorithm which influences the movement of robots so that they go towards the source of the chemical compound. This algorithm uses a graph-based solution for formation control on the robot flock. Using the wind direction, as well as the difference in odor concentration between the robots, they developed three mechanisms to make the robots move towards the odor source. Each robot uses the relative position and the odor readings of the other robot to make the decision in which direction it's supposed to move:

$$\mathbf{u}^i_{goal} = k_w \, \mathbf{u}^i_w + k_c \, \mathbf{u}^i_c - k_r \, \mathbf{u}^i_f$$

$\mathbf{u}_w$ is the wind component of the movement vector:

$$\begin{aligned} \mathbf{u}_w &= R(\theta_w) \begin{bmatrix} 1 \\ 0 \end{bmatrix} \\ &= \begin{bmatrix} \cos(\theta_w) & -\sin(\theta_w) \\ \sin(\theta_w) & \cos(\theta_w) \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \end{aligned}$$

with θ_w the incidence angle of the wind for each robot. $\mathbf{u}_c$ is the influence of the odor concentration on the robot's movement:

$$\begin{aligned} C &= \frac{1}{2} - \frac{1}{1 + e^{-(c_{left} - c_{right})}} \quad \in [-0.5, 0.5] \\ \mathbf{u}_c &= R(\theta_w) \begin{bmatrix} 0 \\ C \end{bmatrix} \end{aligned}$$

with $c_{left,right}$ being the concentration of the left, respectively the right robot. $\mathbf{u}_f$ is the vector controlling the formation around the plume using a dynamic bias:

$$\begin{aligned} \beta^{dyn}_{y,j} &= \beta_{y,j} \cdot \underbrace{(1 + ((c_{left} + c_{right}) - c_{center}))}_{\in[0.5,1]} \\ \mathbf{u}_f &= \sum_{j=1}^{N_{robots}} \mathcal{L}^i_j \cdot \begin{bmatrix} x_j(t) - \beta_{x,j} \\ y_j(t) - \beta^{dyn}_{y,j} \end{bmatrix} \end{aligned}$$

This set of equations only controls the movement of the robot in two dimensions. The goal of this project was to implement a third dimension (z), and test this implementation in Webots as well as in a wind tunnel. Wind tunnel experiments were limited in the fact that there was only one 3D-movement capable device (a rail), and the algorithm for the 3rd dimension was developed with this constrain in mind. The ground robots measured the concentration at ground level, whereas the *flying* robots tries to match it by moving in all 3 dimensions. Vertical movement has been achieved using a dynamical bias as well as a sigmoid function on the odor concentrations:

$$\begin{aligned} C_{vert} &= \frac{1}{2} - \frac{1}{1 + e^{-(c_{upper} - c_{lower})}} \quad \in [-0.5, 0.5] \\ \beta^{dyn}_{z,j} &= \beta_{z,j} \cdot \underbrace{(1 + (c_{upper} - c_{lower}))}_{\geq 1.0} \end{aligned}$$

The algorithm has been tested in Webots as well as in the wind tunnel. In Webots, as long as it can capture some initial concentration, the robot moves towards the boundary of the plume, and then mostly stays there until the source is reached. In the wind tunnel, the movement constrain of the rail (only 20 $[cm]$ of freedom in z) makes it hard to match the ground concentration by moving upwards, and the robot is mostly moving at the maximal height. For both implementations vertical plume centering can not be achieved since the ground robot can not move upwards. Adding more 3D-movement capable robots could improve the success rate of the algorithm, although if quadcopters were to be used, other effects like turbulence needs to be accounted for.

[1] Soares, J. M., Aguiar, A. P., Pascoal, A. M. and Martinoli, A. (2014a). A Graph-Based Formation Algorithm for Odor Plume Tracing. .

[2] Soares, J. M., Aguiar, A. P., Pascoal, A. M. and Martinoli, A. (2014b). A Distributed Formation-Based Odor Source Localization Algorithm - Design, Implementation, and Wind Tunnel Evaluation. .