Simulation of a diffusion driven mobile robot

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Abstract

In this paper, we investigate a possible mechanism to control a mobile robot via a sensory-motor coupling utilizing chemical system. To find the characteristic of correlation between the diffusion process of the chemicals and the behavioural patterns, we simulated the diffusion process and the kinematics of the robot. In comparison to Braitenberg vehicles in which sensory-motor coupling is tightly realised by hardwiring, our system employs soft-coupling.
The mobile robot has two sets of independent sensory-motor units, two distance and light sensors are implemented in front and one motor on each side of the robot. The environment was constructed with a surrounding wall and a light source located at the center. Depending on the design parameters and initial conditions, the robot was able to successfully avoid the wall and light. More interestingly, the diffusion process in the sensory-motor coupling provided the robot with a simple form of memory which would not have been possible with a control framework based on a hard-wired electric circuit.

KEYWORDS - diffusion, mobile robot, simulation, sensory-motor coupling, Braitenberg vehicle

I. Introduction

Reaction-diffusion systems consist of a diffusion and reaction process which can generate a wide range of spatial temporal patterns if coupled in a particular way. They have applications in biology such as pattern formation in morphogenesis, predator-prey in ecology, epidemics and chemical reactions. [1] Yet, Dale et. al [2] showed that reaction-diffusion systems can also be used to provide an organism with a simple form of cognition. In this paper we have gone one step further by using an even simpler diffusion-only system to control a mobile robot. Similar to Dale et al. the chemical system as well as the mobile robot were simulated.
The basic robot was similar to the final version of the third Braitenberg vehicle. [3] It had two pairs of sensors, one measuring the distance to the surrounding wall and the other pair measuring the intensity of light in front of the robot. This set up made it even simpler than the final version of the third Braitenberg vehicle because only two of the four original sensor pairs were implemented. However, instead of a direct hard-wired electronic connection between the sensors and the motors, the sensory-motor coupling of the mobile robot was implemented by soft-coupling. Meaning, that the sensor values were converted into values representing the amount of two chemicals dropped into a two dimensional chemical system. At two specific points the concentration of the chemicals was measured and then used to control the speed of the motors. The nature of the chemical diffusion process introduced a certain time-delay to the sensory-motor coupling of the mobile robot which prevented the robot from moving continuously.

The rest of the paper is structured as follows: In section II the characteristics of the simulated robot and the chemical system as well as the algorithm for the sensory-motor coupling are described. Section III illustrates the influence of the design parameters and initial conditions on the behaviour of the robot and describes the produced behaviour. Finally, Section IV draws conclusions and outlines future perspectives of the present work.

II. Methodology

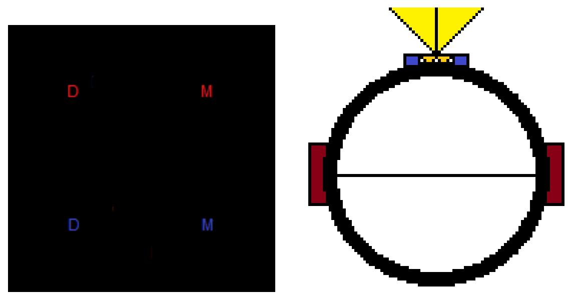
A. The mobile robot

The simulated robot had a round shape with a diameter of 0.1 lenght units. It had two motors at its sides and two distance and light sensors at the front. One of the distant sensors was one degree to the left of the driving direction and the other one degree to the right. The light sensors were mounted at the front next to each other, each covering a range of $45°$. (see figure 1(b))

B. The chemical system

The chemical system was implemented as a quadratic plate with a grid size of 100 length units and periodic boundaries. The minimum concentration of the chemicals was 0 and the maximum concentration 1. Four special positions, a dropping and a measurement point for each chemical, existed in the chemical system. (see figure 1(a)) At the dropping points the concentration was increased and at the measurement points it was set to zero after each measurement.

The distance between the dropping and measurement point and the diffusion rate was the same for both chemicals. This led to the fact that the time it took for a newly dropped amount to reach the measurement point could only differ because of a difference in the concentration of the two chemicals in intermediate positions.



(a) (b)

Fig. 1. Illustration of the simulated chemical system and robot. The dropping (D) and measurement (M) points of chemical U and V are shown in red and blue, respectively.

C. Algorithm for sensory-motor coupling

The algorithm for the sensory-motor coupling was the following

1. Determination of values for distance and light sensors.
2. Dropping of U and V depending on the calculated sensor values.
3. Calculation of the diffusion of the chemicals.
4. Calculation of the new orientation of the robot depending on the concentration at the measurement points.
5. Movement of the robot into the new direction.

1) Sensor values: The values of the distance sensors corresponded to the distance to the wall. In contrast, the light sensor values corresponded to the intensity of the light which is equal to the inverse of the distance of the sensors from the light source.

2) Dropping of chemicals: The left sensors were determining the dropping amount of U and the right sensors the amount of V using the following formula.

$$A = (\frac{1}{D} + L) * \frac{1}{R} \tag{1}$$

where A was the amount which would be dropped, D the value of the distance sensor and L the value of the light sensor. By using the inverse of the distance the amount dropped was increased the closer the robot came to the wall and decreased the bigger the distance between the robot and the wall got. The last term R was a scaling factor, called *drop dividor*, which made it possible to decrease the amount dropped for both chemicals.

3) Diffusion: The simulation used a forward Euler integration.

$$\begin{aligned} \frac{\partial u}{\partial t} &= D_u \nabla^2 u \\ \frac{\partial v}{\partial t} &= D_v \nabla^2 v \end{aligned} \tag{2}$$

where ∇^2 was the Laplacian operator. The following Laplacian matrix was used for the simulation.

0.05	0.2	0.05
0.2	-1	0.2
0.05	0.2	0.05

4) Orientation Change: The orientation change of the robot was calculated using the following formula:

$$\Delta O = [U] - [V] \tag{3}$$

where *[U]* and *[V]* represented the concentrations of the chemicals at the measurement points and ΔO the orientation change in degree. After the measurement, the concentrations at the measurement points were set to zero to prevent a global concentration of 1. Figure 2 exemplifies the orientation calculation.

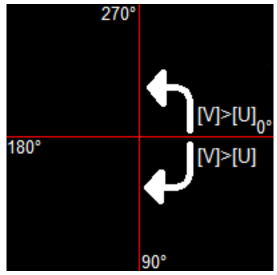


Fig. 2. Overview of the turning behaviour for the ratio of [U] and [V] at the measurement points.

5) Movement of robot: The movement of the robot happened only during the last step of the algorithm. This was done to ensure consistency with the behaviour of a robot connected to a real chemical system in which the time needed for the diffusion of the chemicals would prevent a continuous movement.

III. Results

A. Effect of design parameters and initial conditions

The global initial concentration of both chemicals was always set to 0. Thus, in contrast to the following parameters it was not used to influence the behaviour of the robot.

1) The diffusion rate: The diffusion rate had an influence on the speed and strength of the reaction of the mobile robot. By always setting the diffusion rates of both chemicals to the same value it was ensured that no turning direction was favoured. The maximum diffusion rate in the simulation was one and the minimum zero.

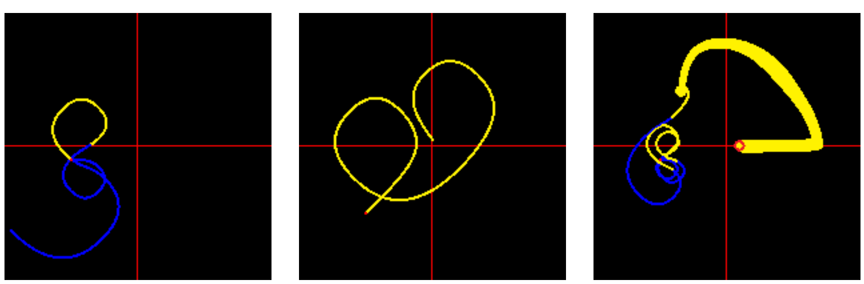
2) Initial robot orientation and position: The initial orientation of the robot had an influence on the complexity of the robot behaviour. For an initial orientation of $0°$, $90°$, $180°$ or $270°$ with no light measured by the sensors the robot would move straight into the wall. When the robots initial position was on one of the two diagonals and its initial orientation was $45°$, $135°$, $225°$ or $315°$, it would also move in a straight line. Resulting in a collision with the wall or light source.

3) Drop dividor: The drop dividor was used to reduce the amount dropped for both chemicals. Similar to the diffusion rate it had an influence on the reaction speed and strength of the robot.

4) Speed: The speed of the robot determined the time the robot had to react. If the speed was high the dropped chemicals did not had enough time to reach the measurement points which led to unsuccessful behaviour. For very low speed the robot stayed on its initial position while changing its orientation continuously.

B. Behaviour of the mobile robot

Depending on the configuration of the design parameters and the initial conditions the robot showed different behaviour and was driving forms (see fig. 3) which were similar to the forms Braitenberg imagined for his vehicles. [3]



(a) (b) (c)

Fig. 3. Forms driven by the mobile robot. Initial position is red. Left turn is shown in yellow and right turn in blue.

For most configurations the robot was not able to avoid the wall and light source. Although, it survived sometimes several million iterations. For the few successful configurations the robot always showed the same behavioural pattern.

1) Several changes of the turning direction.
2) One chemical got a globally higher concentration which prevented any future direction changes.
3) Both chemicals started to oscillate which led to the robot driving in a small circle for an infinite time.

The behaviour of the system was similar to a simple kind of memory because past sensor values had an influence on the future turning direction. The longer the robot turned into one direction the longer it took until the robot implemented a direction change when the sensor values pointed into the other direction. Therefore, the concentrations indicated which direction was a good decision in the past by preventing a collision.

Figure 3(c) is an example for successful behaviour. It has all the previously described phases. Phase 2 was reached after 130,000 iterations when the robot was turning left and unable to change the direction. 7.5 million more iterations were needed until the robot entered phase 3.

The concentration at the measurement points for the example illustrated in figure 3(c) is shown in figure 4 for 15 million iterations. The moment where the concentrations prevented any new direction is directly after the steep increase at the beginning. While V stays constantly at 0.211, U continues to increase until it reaches its maximum of 0.185. This point can be found in 3(c) where the robot stopped to move down and started to move towards the middle of the environment. The next phase after the concentrations of both chemicals had decreased represents the final circle after 7.5 millions iterations and was characterized by a constant oscillation of both concentrations.

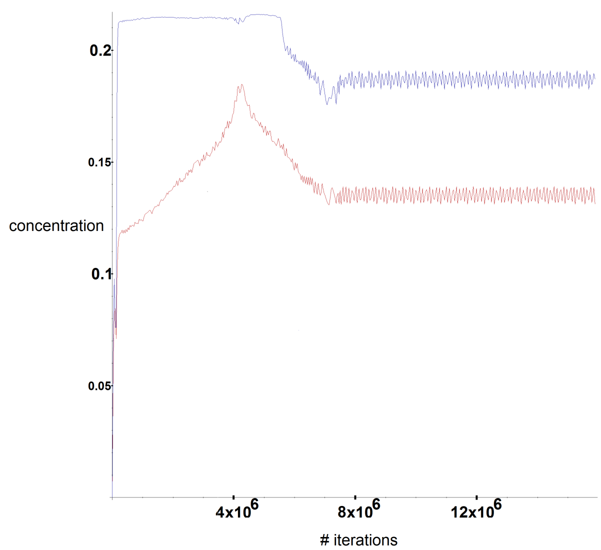


Fig. 4. Concentration at the measurement points. [U] in red and [V] in blue.

IV. Conclusions and Future work

Although there was no reaction between the chemicals, the system was able to create more complex behaviour then would have been possible with the use of a direct hard-wired sensory-motor coupling. However, only a few of the configurations were able to provide the robot with the ability to avoid the wall and light.
A next step would be the substitution of one of the simulated components, the robot or the chemical system, by a real component. If the results are similar to the results obtained with the simulation a further step would be the use of only real components. Finally, the obtained results can be used to introduce a reaction between the chemicals which will expand the complexity of the shown behaviour.

References

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