LIQUID BRAINS FOR ROBOTS

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Amongst many branches of physics-based and nature-inspired computing, e.g. quantum, DNA, field and swarm computing, reaction-diffusion, or chemical, computing devices are the most successful with experimentally fabricated prototypes of amorphous, liquid-phase, wave-based unconventional computational devices having been constructed. Chemical computing devices realised in thin-layer geometries form a unique class of wet parallel processors. They have parallel input of data (spatial distribution of the reactant concentrations), massively parallel information processing (via spreading and subsequent interaction of waves) and parallel output of results (commonly, the results are represented by patterns of reactants or a coloured precipitate/product that enables the use of conventional optical reading devices). Tasks that can be solved by these chemical computers vary from image processing and path planning to the implementation of logical functions, see review in [1,2].

In this paper we deal with chemical controllers for mobile robots. The design of the chemical controllers explores the basic features of the space-time dynamics of travelling waves, wave generation and more specifically wave interactions. Laboratory prototype implementations of chemical controllers have been produced which employ the inherent abilities of these reaction-diffusion media to conduct information processing via a parallel input-output interface and utilising unreliable elementary computing processors (micro-volumes). Namely, we report the development of experimental reaction-diffusion processors specialised in the guidance of a mobile robot towards a source of stimulation. The results of the study provide a background for the further development of liquid-phase chemical controllers that would ultimately have responsibility for the robot's vision and navigation.

To make a liquid controller for mobile robots we employed the Belousov-Zhabotinsky (BZ) medium [3]. The BZ reaction exhibits spontaneous oscillatory behaviour. The mechanistic details are complex but effectively involve a fine balance between an autocatalytic oxidation process and an autocatalytic inhibitor. Just outside the conditions required for spontaneous oscillatory behaviour the BZ reactions exhibits a property known as excitability. An excitable system has a steady state and is stable to small perturbations, however if the perturbations exceed a critical threshold then the system responds with an excitation event --- in a thin layer architecture this results in a circular wave travelling from the source of stimulation.

We tested decision-making capabilities of BZ medium in experiments on simple taxis (the directional movement of a creature in response to an external stimulus); implementation of positive taxis is the first step in the realisation of an intelligent chemical controller to be utilised in application of autonomous systems in real life. Taxis is implemented as follows. Assume, that the chemical medium, constituting the liquid brain, is sensitive to certain stimulus. Every micro-volume of the reactor's edges excites depending on the intensity of the stimulation, i.e. proportional to a relative distance from the source of stimulation. Therefore, micro-volumes at those edges of the reactor, which are closer to the source of stimulation are excited and generate spreading waves of excitation that travel in the reactor space. If velocity vectors of the generated wave fronts are inverted they indicate the direction towards the source of stimulation. A simple summation of the inverted velocity vectors gives us a global vector, indicating the position of the stimulation-source, this vector is then used as a base to rotate a robot, hosting the reactor. The waves are generated continuously during the robot movements therefore the direction vector may be recalculated continuously as the robot moves. Thus in theory the robot can even be orientated towards and follow a mobile target. This idea is illustrated in Fig. 1, where a source of stimulation, contours of wave fronts, wave velocities and direction vector to target are indicated.

The robot, equipment with BZ-medium based liquid brains, exhibits three distinct types of behaviour: stochastic search (at this stage the excitation waves had just formed and were starting to spread in the chemical medium), approaching target source of stimulation (oxidation wave fronts fill the whole reactor space) and confused motion (bubbles of formed by the reaction occupy large area of the reactor and cause significant errors in vector calculation).

To conclude, we designed liquid chemical controllers for robots, and demonstrated in scooping experiments that excitable chemical media can be successfully applied to controlling mobile robots. This may form a basis for future designs of fully functional liquid-phase robotic brains.

References

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