Coupled Oscillators and Walking Control: A Hardware Implementation of a Distributed Motor System

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A technology is presented, mathematically analyzed and implemented for the generation of movement patterns of autonomous robots. We discuss this by looking at a simple example.

Despite huge success in robotics and artificial neural networks, biological systems are still far superior to artificial ones. Some of the important features that are responsible for this are distributed control, parallel computation and a broad interface to the motor system from the sensory system.

We propose simple 'neurons' that can be coupled to form networks of oscillators inducing walking behaviour in legged machines. Such a 'neuron' is shown in fig.1B. It consists of a differentiator and an inverter. It reacts to a voltage step input with an active low pulse of duration T, which is proportional to the time constant $\tau = RC$ and can be modified thereby.

An example of a walking controller constructed from these 'neurons' is shown in fig.1B. Connecting the output of one 'neuron' to the input of another one and vice versa forms a self triggering oscillator with frequency $\nu = 1/(A_1 R_1 C_1 + A_2 R_2 C_2)$; $A_1, A_2 = const.$ The duty cycle is determined by the ratio between the two time constants of the oscillator. It is different from 1/2 for $R_1 C_1 / R_2 C_2 \neq 1$. The outputs of this oscillator are two mirror image step functions that can drive a motor (via buffers) and cause it to turn back and forth. To form the controller, two such oscillators are coupled such that a phase lag between them can be achieved (as shown in 1B). This phase lag is proportional to the time constants set by the coupling resistances. Assuming a duty cycle of 1/2, it is: $\phi = B_2(R_3 C_3 + R_4 C_4)/2B_1(R_1 C_1 + R_2 C_2)$; $B_1, B_2 = const.$ The duty cycle of the 'slave' oscillator is different from 1/2 for $R_3 C_3 / R_4 C_4 \neq 1$.

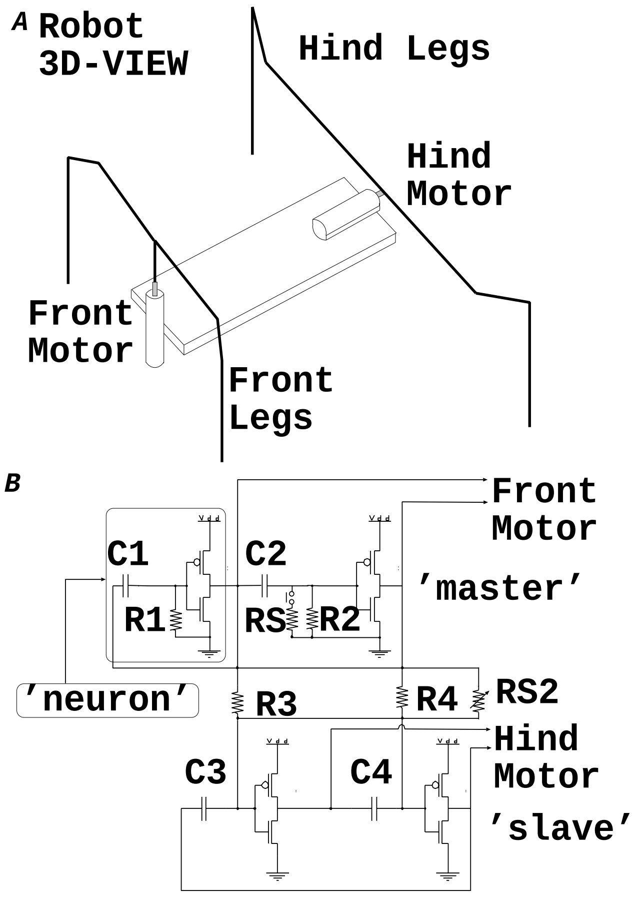

Figure 1: Sketch of A: Robot, B: controller

The output of the 'master' oscillator drives (via buffers) the front motor of the robot, the output of the 'slave' oscillator drives the hind motor. Each oscillator therefore drives the legs of one girdle. A sketch of the robot is shown in fig.1A. Since the legs of each girdle are attached to each other, the possible walking gaits are restricted to 'quasi-walks'. The behaviourally relevant variables are the phase lag between the two girdles (which sets the gait) as well as the frequency and duty cycle of the leg movement. A duty cycle different from 1/2 can be used to implement turning.

Sensory information can be integrated directly by changing relevant time constants. Two examples of this are given in fig.1B. The sensor with resistance R_S is implemented as a tactile sensor that changes the duty cycle of the master, which results in turning. Behaviour such as obstacle avoidance can be achieved in this way. The other sensor (R_{S2}) changes the gait. It can be implemented using a photo diode, e.g. causing the robot to walk with a different gait in darkness than in light. Sensory information can also be integrated indirectly via more complex networks that pre-process it to eventually change the relevant time constants.

We have shown an example of a simple autonomous machine, using a distributed controller to determine the entire behaviour of the robot with a small number of parameters, including turning and walking gaits.

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