Supplementary material for the paper: Evolving group transport strategies for e-puck robots: moving objects towards a target area

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Abstract. This paper describes a set of experiments in which a homogeneous group of simulated e-puck robots is required to coordinate their actions in order to transport cuboid objects towards a target location. The objects are heavy enough to require the coordinated effort of all the members of the group to be transported. The agents' controllers are dynamic neural networks synthesised through evolutionary computation techniques. The results of our experiments indicate that the most effective transport strategies generated by artificial evolution are those in which the robots exploit occlusion by pushing the objects across the portion of their surface, where they occlude the direct line of sight to the goal. The main contribution of this study is the analysis of the relationships between the characteristics of the object (i.e., mass and length), the morphology of the robots, and the group performance. We also test the scalability of the occlusion-based transport strategies to group larger than those used during the evolutionary design phase.

1 Previous work

A detailed description of the simulation environment, of the robot model, including noise applied to sensors and motors, as well as results of all re-evaluation tests, and movies for the simulation and real robots can be found in supplementary materials of our previous work *Design and Analysis of Proximate Mechanisms for Cooperative Transport in Real Robots*. Reader can access to the supplementary contents by following the URL `https://www.aber.ac.uk/en/cs/research/ir/dss/#swarm-robotics`

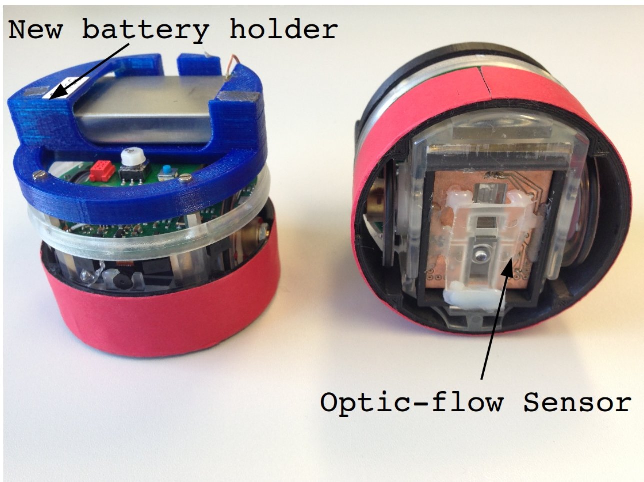

Fig. 1. The e-puck robot with optic-flow sensor.

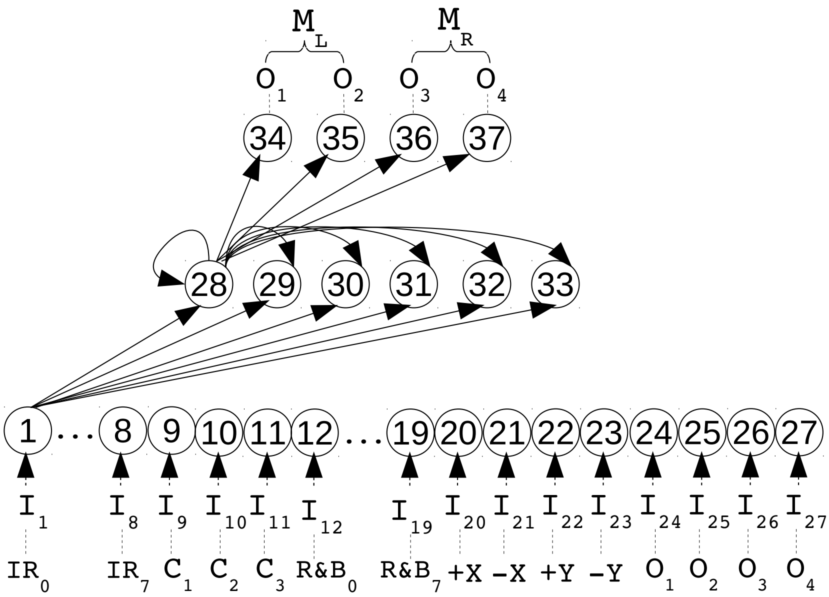

Fig. 2. The robot controller. The continuous line arrows indicate the efferent connections for only one neuron of each layer. Robot sensors to sensor neurons correspondence is indicated underneath the input layer, with IR_i referring to the infra-red, C_i to the camera sensors, $R\&B_i$ to the range and bearing, +X, -X, +Y, -Y to the optical flow sensor, and O_i referring to the output of the network at previous time step.

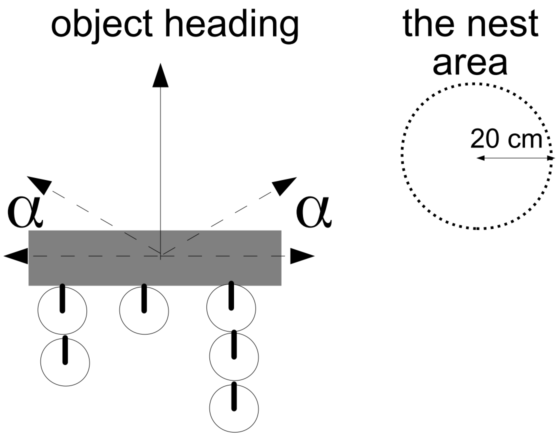

Fig. 3. Experimental scenario; the empty circles refer to the robots, the grey rectangle refers to the object to be transported, the dashed arrows delimit to the angles (α) within which the nest can appear, the dotted circle refers to the nest.

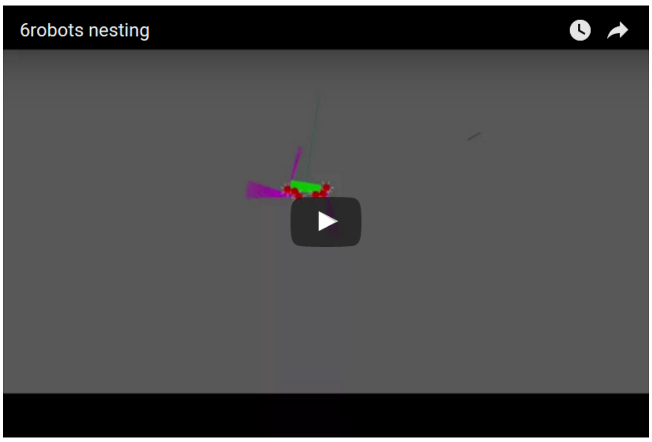

Fig. 4. Video from simulation showing group of 6 robots (red cylinders) transporting object (green elongate cuboid) to the nest (yellow circle). Green line refers to the current object heading. Black line links the object centroid and the nest centroid. *Alpha* is the smallest angle between the green and black line. Wight rays shining from the robots refer to the proximity sensors. Pink rays refers to the robot camera field of view. To play the video, click on the image or use the following URL `https://www.youtube.com/embed/wX0p6Jjjocc`

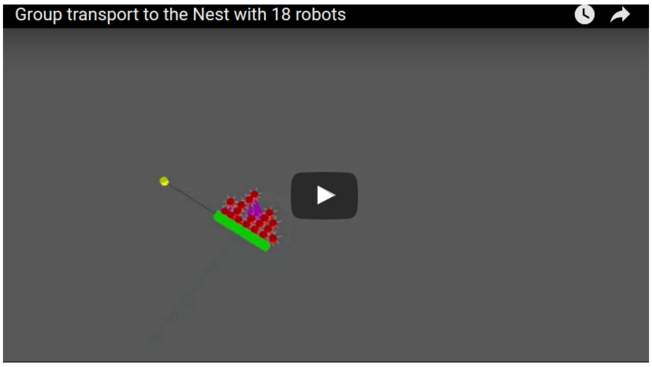

Fig. 5. Video from simulation showing group of 18 robots transporting object of 60 cm length and 2500 g mass. To play the video, click on the image or use the following URL `https://www.youtube.com/embed/iNDBYRLse8c`

Fig. 6. Video showing group of 6 real e-puck robots transporting an elongate cuboid object of 40 cm length and 600 g of mass in 220x220 cm arena. Once, the group coordinate and the transportation begin, we place another robot (i.e., nest) to the left or to the right of object. This robot emitting an infra-red signal using Range and bearing board. This signal induces the transporter robots to transport the object toward that robot (i.e., nest). To play the video, click on the image or use the following URL `https://www.youtube.com/embed/t8wbicHdRFk`

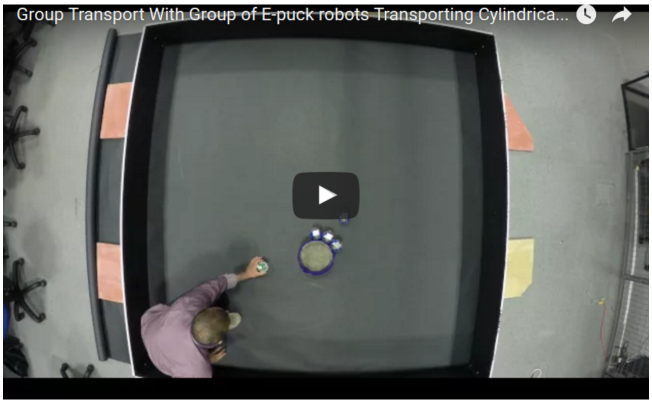

Fig. 7. Video showing group of 4 real e-puck robots transporting a cylindrical object of 22 cm diameter and 350 g of mass in 220x220 cm arena. Once, the group coordinate and the transportation begin, we place another robot (i.e., nest) to the left or to the right of object. This robot emitting an infra-red signal using Range and bearing board. This signal induces the transporter robots to transport the object toward that robot (i.e., nest). To play the video, click on the image or use the following URL `https://www.youtube.com/embed/QiaaQPf_r3Ik`