Supplementary material for the paper: Design and Analysis of Proximate Mechanisms for Cooperative Transport in Real Robots

Muhanad H. Mohammed Alkilabi, Aparajit Narayan, and Elio Tuci

Compututer Science Department, Aberystwyth University, Aberystwyth, UK
{mhm1,apn3,elt7}@aber.ac.uk

Submitted to the Tenth International Conference on Swarm Intelligence (ANTS) 2016

Abstract. This paper describes a set of experiments in which a homogeneous group of real e-puck robots is required to coordinate their actions in order to transport cuboid objects that are too heavy to be moved by single robots. The agents controllers are dynamic neural networks synthesised through evolutionary computation techniques. To run these experiments, we designed, built, and mounted on the robots a new sensor that returns the agent displacement on the x/y plane. In this object transport scenario, this sensor generates useful feedback on the consequences of the robot actions, helping the robots to perceive whether their pushing forces are aligned with the object movement. The results of our experiments indicated that the best evolved controller can effectively operate on real robots. The group transport strategies turned out to be robust and scalable to effectively operate in a variety of conditions in which we vary physical characteristics of the object and group cardinality. From a biological perspective, the results of this study indicate that the perception of the object movement could explain how natural organisms manage to coordinate their actions to transport heavy items.

1 The Task and the Simulation Model

This study focuses on an object-transport task in which a group of four robots are required to push an elongate cuboid object which is too heavy to be moved by a single robot. During evolution, The robots are initially positioned in a boundless flat arena at 50cm from the object. Such that, their starting positions correspond to randomly chosen points on a circle's circumference of 50 cm radius that has the object in it's centre. This circle is divided in four equals parts. Each robot is randomly placed in one part of this circle with random orientation in a way that the object can be within an angular distance of $\pm 60°$ from its facing direction. These criteria should generate the required variability to develop solutions that are not sensitive to the robots initial positions. The objective of the robots is to move the object 2 m away from its initial position. The object mass is set so that the coordinated effort of all four robots is required to move the object. The robots can perceive the object with their camera, and when sufficiently close to it, they can sense it with their infra-red sensors. The task requires the robots to independently search for the object and move towards it. Once in the proximity of the object, the robots have to coordinate their actions in order to push the object by exerting the forces required to transport it as far as possible from its initial position.

To take into account the dynamic aspects of this group transport scenario (e.g., forces, torque, friction, etc.), the agents and their environment have been simulated using *Bullet* physics engine. The object has a cuboid shape (30cm length, 6cm width, 6cm height) with a mass of 600g. Our simulation models an e-puck robot. The robot model consists of three rigid bodies, a cylindrical chassis (3.55cm radius, 6.2cm height 200g mass), and two motorised cylindrical wheels (2.05cm radius, 0.2cm height, 20g mass) connected to the chassis with hinge joints. Both wheels can rotate forwards and backwards at a maximum speed of 8cm/s.

Each robot is provided with eight infra-red sensors (IR^i with $i = \{0, .., 7\}$), which give the robot a noisy and non-linear indication of the proximity of an obstacle (e.g., the object or another robot). The IR sensor values are computed using a non-linear regression model of the sensor readings collected from the real e-puck. Once the values are computed, they are incorporated with noise in two different levels, one is for active IR sensors (i.e. sensors have objects within their range) which are incorporated with uniformly distributed random noise of level $[25\%, -25\%]$. Other noise level is for inactive IR sensors which are incorporated with Gaussian distribution random noise of level $[7\%, -7\%]$. The mouse sensor reading values (i.e., +X, -X, +Y, and -Y) are also subject to uniformly distributed random noise in the range of $[-0.025\%, 0.025\%]$. Each robot is also equipped with a camera that can perceive coloured items (i.e., the object which is green, or robots which are all red). The camera has a receptive field of 30°, divided in three equal sectors C_i, with $i = \{1, 2, 3\}$, each of which can return one of four possible values: 0 if no item falls within the sector's field of view; 0.4 if one or more red items are perceived; 0.7 if a green item is perceived; 1.0 if red and green items are perceived. The camera can detect coloured objects up to a distance of 50cm.

Fig. 1. Video showing groups of 3, 4, 5 and 6 real e-puck robots transporting a cuboid object placed in the centre of bounded square arena (220 cm side length). The maximum time the trail can last is 180 s and consider successful if the group manages to transport the object up to 1 m distance from it's starting position. The object's position is tracked using *Vicon* tracking system. To play the video, click on the above image or use the following URL `https://www.youtube.com/embed/B1bdGegkgXY`

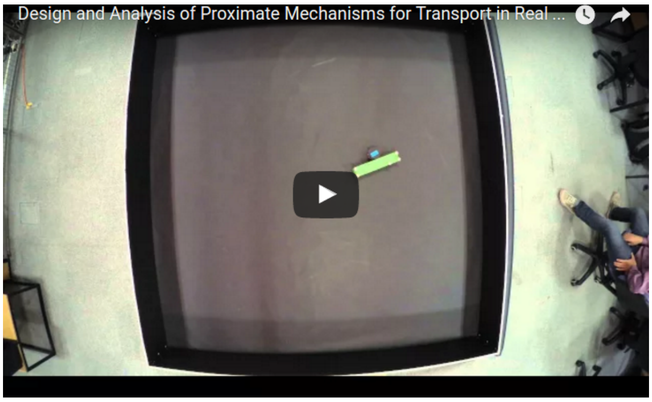

Fig. 2. Video showing Behavioural tests conducted with single e-puck robot. In test L (light), we use 30 cm length, and 150 g mass object. In test H (heavy), we use 30 cm length, and 600 g mass object. In test R (long), we use 400 g mass, and 40 cm length object. During 60 s of each trial, we record the number of repositioning events the robots made in order to measure the robot's persistence when the physical characteristic of the object is changed. To play the video, click on the image or use the following URL `https://www.youtube.com/embed/9ucaxT-Ldmo`

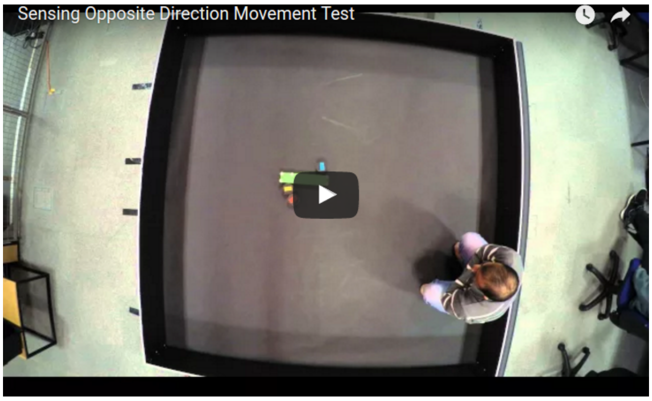

Fig. 3. Video showing sensing the opposite direction test. In this test, single e-puck robot placed on one side of the object and another two e-puck robots placed on the opposite side. We record the reading from the optic-flow sensor and number of repositioning events from the two front infra-red sensors. The objective is to measure how long does it takes the robot (in term of repositioning events) from the point of first touch of the longest side of the object (i.e., when the robot sensing the opposite movement of the object) to the point when the robot touch the other longest side of the object(i.e., the robot pushes on the same the direction of the other two robots). To play the video, click on the image or use the following URL `https://www.youtube.com/embed/GAarL3yfWo0`