

Experiments on Robotic Multi-Agent System for Hose Deployment and Transportation

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Abstract This paper reports an experimental proof-of-concept of a new paradigm in the general field of Multi-Agent Systems, a Linked Multi-component Robotic System. The prototype system realizes a basic task in the general framework of a multi-robot hose transportation system: the transportation along a linear trajectory. Even this simple task illustrates some complexities inherent to the general task of hose transportation. Artificial Vision is used to perceive the state of the system composed of the agents and the hose. The robotic agents are autonomously controlled by means of a scalable control heuristic. The system is able to deploy and transport a passive object simulating a hose in straight line, avoiding the formation of loops and dragging between robots.

1 Introduction

Multi-Agent Systems (MAS) have been proposed in several application domains as a way to fulfill more efficiently a task by cooperation between several autonomous agents [7]. This paradigm has a very direct application in robotics, as the physical limitations of the real-life robots and the environments they are supposed to work in impose severe restrictions to their capability to fulfill some tasks, up to the extent that there are complex tasks that can not be accomplished by a single robot and must be performed necessarily by a multi-robot system [2].

In the last two decades a lot of effort has been put in transferring the MAS paradigm to mobile robotics. There are several reviews giving different categorizations [2, 1, 6, 3] focusing on different aspects of the multi-robot systems. Recently, in [3] a categorization of Multi-component Robotic Systems (MCRS) has been done

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focusing, among other aspects, on the way the robotic agents are physically connected, identifying three main types of MCRS: Distributed, Linked and Modular.

This categorization presents an interesting novelty: while the Distributed and Modular MCRS are familiar concepts, representing groups of robots unlinked and joined by a rigid component, respectively, the Linked MCRS is a new category, not previously identified in the literature and characterised by a linking passive element between robots. This new category theoretically shows some new issues coming from this passive element that the system's agents have to cope with and we are starting to deal with them from several points of view. In [5, 4] we addressed the problem of modelling and derived the formal inverse kinematics and dynamics of this kind of robots. In this paper we dwell more on the physical realization of a proof-of-concept of a Linked MCRS with a concrete set of robots and a piece of electric cable as the passive linking element.

In the following section 2 a brief description of the hose transportation problem is given. In section 3 we detail the specifics of the approach followed to implement this proof-of-concept, giving a description of the artificial vision perception system and the agents' control heuristic, finishing with an example of operation. Finally, in section 4 we discuss the specific traits of this kind of multi-agent robotic systems identified through the implementation of this proof-of-concept.

2 Robotic Multi-Agent System for hose transportation

The transportation, deployment and manipulation of a long¹ almost uni-dimensional object is a nice example of a task that can not be performed by a single robotic agent. It needs the cooperative works of a team of robots. In some largely unstructured environments like shipyards or large civil engineering constructions a typical required task is the transportation of fluid materials through pipes or hoses. The manipulation of these objects is a paradigmatic example of a Linked MCRS, where the carrier robot team will have to adapt to changes in the dynamic environment, avoiding mobile obstacles and adapting its shape to the changing path until it reaches its destination.

The general structure and composition of this hose transportation robotic MAS would be that of a group of robots attached to the hose at fixed or varying points. The robots would search for space positions in order to force the hose to adopt a certain shape that adapts to the environment, while trying to lead the head of the hose to a goal destination where the corresponding fluid will be used for some operation. The changing environment conditions may force changes in the hose spatial disposition, to which the robots should be able to react. This general form can take multiple implementations depending on several elements of its design:

¹ The adjective "Long" used here is relative to the size of the individual robots. The object's length must be some order of magnitude greater than the robot's size.

- Robot-hose attachment: Robots could be fixed to a point of the hose, they can move along it, or they can pull it through special gripping mechanisms.
- There can be a centralised control for all of the robots or, in a true MAS approach, it can be decentralised, each robot taking its own control decision.
- Robots can be homogeneous or heterogeneous, having different configurations and tasks (e.g., “pulling” robots, which tow the hose, and “cornering” robots, which take fixed positions and give shape to the hose).
- Perception can be global, with some agent acquiring a global view of the system, or local, with every robot acquiring information of its close surroundings.

Our research group is actively involved in studying the hose manipulation problem from diverse points of view, producing modelling and simulation of the hose-robots dynamics and some problem characterizations [5, 8, 4]. However, the starting point to achieve this system on a real robotic platform is the physical realization using real robots of a vision controlled robotic MAS which faces the basic non-trivial issues in this hose transportation problem.

3 Proof-of-concept prototype and experiment

For the physical realization of this proof-of-concept we have defined the basic problem to solve: to control a robotic MAS whose objective is to perform the transportation of the hose in a straight line in an environment without obstacles from an initial arbitrary configuration of hose and robots. In case that the robots are fixed to the hose or that an individual robot is not powerful enough to pull it or the initial configuration of the hose is arbitrary, this task has to be necessarily performed by several robots. Several robots have to be controlled to guarantee a certain hose configuration and each individual robot motion has to be controlled in order to keep a desired formation. Thus, although the task is the simplest one that can be defined, it is a non-trivial task which poses several problems whose solutions are the cornerstones of the solution of more sophisticated ones. Besides, we will need to deal with the restrictions that the real robot’s embodiment impose, which must be coped with in order to obtain a working system realizing the proposed task.

The task defined above has rather diverse solutions depending on the actual robots employed and the actual physical features of the passive element. In this section we give an account of the hardware used, the image analysis procedures applied to obtain the visual feedback and the control heuristic applied to define the control strategies.

3.1 Hardware and communications

The experimental solution to this problem was implemented using three small SR1 educational robots. Each robot was attached to an electrical cable of 1 cm. of di-

ameter, which takes the place of the hose, by means of a bearing which allows the robot to rotate freely under it. One camera was placed on a 2.5 meters high mobile stand, facing down at an angle of around 60° and capturing about 2-3 meters of the floor in front of it. The camera was attached to one laptop PC which performed the centralised perception and control processing. Control commands were sent to the robots using a relatively noisy RF wireless channel. The robot’s compass information is used in the “follow the leader” strategy described below.

3.2 Perception

The centralised perception is provided by a single camera that captures the scene encompassing the three robots and the hose. The images acquired are segmented in search for the three robots and the hose. This segmentation process assumes several conditions on the environment’s configuration: blue robots, dark (non-blue) hose, uniform floor of bright color (non-blue) and white, uniform illumination. Image segmentation is composed of two separated processes, one for the detection of the robots and the other for the localization of the hose.

Robot’s segmentation

For the segmentation of the robots we are mainly interested in avoiding the effect of strong reflections on the floor and enhance the image color contrast in order to bring out the blue robots from the bright floor. This is achieved by means of a pre-processing step in which a Specular Free (SF) image [10] is created. We follow the Dichromatic Reflection Model (DRM) [9], where images are the sum of two components: the diffuse component (which models the chromacity of the observed surfaces) and the specular component (which models the chromacity of the light source which illuminates the scene). Assuming a white light source, in this algorithm we profit from the characteristics of the RGB cube, as pixels corresponding to reflections (and bright surfaces close to white color) will be very close to the gray color axis that goes from point (0,0,0) to point (1,1,1) of the RGB cube while pixels corresponding to diffuse components in the image will move away from it and will be closer to the pure color axes. This property is used to reduce the intensity of the specular pixels and improve the intensity of the diffuse ones proportionally to their distance with the grayscale axis. Given an input RGB image $X = \{x(i, j)\}$, where $x(i, j) = \{r_{ij}, g_{ij}, b_{ij}\}$, a chromatic image $C = \{c(i, j)\}$ is computed as

$$c(i, j) = \max(r_{ij}, g_{ij}, b_{ij}) - \min(r_{ij}, g_{ij}, b_{ij}), \quad (1)$$

in this equation, using normalised values, white/gray pixels will have value $c(i, j)$ close to zero, while colored regions, corresponding to diffuse components, will be close to one.

The RGB image is then transformed to HSV space and its intensity channel is replaced with the computed chromatic image C , so that white/gray pixels become very close to black. This HSV image is then transformed back to RGB space. Since we are looking for blue robots, they can be easily found in the SF image looking for the regions with highest intensities in the B channel. The result of this step is a collection of boxes $\mathbf{R} = \{R_1, \dots, R_n\}$ giving the regions of the image containing the location of the robots. Robot position p_i will be the centroid of that region. When processing a sequence of images, the robot detection process is done in the neighborhood of the previous image detected boxes.

Hose segmentation

The segmentation of the hose takes advantage from the strong contrast of a dark object over a bright floor. Given the original RGB frame and the regions obtained from the robot's segmentation, hose's segmentation is performed by the following processing steps: (a) The image is binarized, white pixels code the hose detection. (b) The binary image is skeletonized. (c) Regions of the skeletonized binary image are identified and labeled. (d) Discard very small regions. (e) Discard regions that do not connect two of the boxes found before containing a robot. Each region obtained after this process is considered a segment of the hose, we denote them $\mathbf{S} = \{S_1, \dots, S_{n-1}\}$ where segment S_i connects robot boxes R_i and R_{i+1} .

3.3 Control heuristic

Due the limited computing capabilities of the robotic platform used, the control commands are determined in a separate single computer and then communicated to the robots. However, each of the actions of the robots is computed independently, without taking into account the state of the other robots, as if they were computed by each of the independent agents. Each robot's control will be determined only by the perception of the segment of the hose that is immediately ahead of it and the information about the orientation of the leader. In this way the system is very scalable and can be extended to any number of robots.

The trajectory of the robots will be controlled by a "follow the leader" strategy. The leader will be remotely controlled and the remaining robots will follow its orientation: at each time step, the tema robots will check if they have the same orientation as the leader, using their compasses. They will reorient themselves trying to align with the leader in case they are not.

Each robot's speed will be given by a control heuristic that takes into account the state of the hose segment ahead of it. This state is a function of the curvature of the hose segment. Given an image hose segment $S = \{s_1, \dots, s_m\}$, where s_j is a pixel site coordinates, we define the curvature c of the segment S as the proportion

between the maximum distance d_h from the hose segment points s_j to the line L_{p_1, p_2} that crosses both robot's positions (p_1, p_2) and the distance between the robots d_r :

$$c = \frac{d_h}{d_r}, \quad (2)$$

where $d_h = \max_i \|s_i - L_{p_1, p_2}\|$ and $d_r = \|p_1 - p_2\|$.

This is equivalent to obtain the ratio of the sides of the rectangle that encloses the hose segment and has the length of the distance between the robots. Being it a ratio value, it is not so influenced by the perspective.

This heuristic underlying reasoning is that if two robots are too close, the hose segment between them will fold and increase its curvature, with the risk of forming loops. The robot at the rear of the hose segment must reduce its speed. On the other hand, if the two robots attached to the hose segment are separated enough the hose segment will be very close to the straight line. A segment too tight will produce dragging between the robots. In this case, the rear robot should accelerate to ease the tension of the hose. Three rules determining the consequent robot speed were defined over the values of this proportion c :

- $c \leq 0.15$: The hose segment is too tight. The rear robot takes *fast* speed trying to shrink the hose to avoid dragging the front robot.
- $c \geq 0.30$: The hose segment has shrunk too much. The rear robot *stops* and waits for the hose to stretch to prevent the formation of loops.
- $c \in (0.15, 0.30)$: The hose has the correct length. The rear robot takes *cruise* speed and continues advancing.

3.4 Experiment realization

In figure 1 an example of the realization of the hose transportation task defined above is shown. In each frame, the robots are marked with the action they are taking and the curvature of their respective hose segment. Detected hose segments were marked in red in the original colored video. The six frames are extracted from the video generated in the test and show how the system reacts to the different states that the hose takes:

- Figure 1a: Starting position. The leader starts towing the hose, while the 2nd and 3th robots wait for it to stretch enough.
- Figure 1b: The first segment's curvature falls below 0.30 ($c_1 = 0.27$). The 2nd robot starts advancing at cruise speed. The 3th robot keeps waiting ($c_2 = 0.67$).
- Figure 1c: The first segment is too stretched ($c_1 = 0.11$). The 2nd robot accelerates to fast speed to shrink it. The 3th robot keeps waiting ($c_2 = 0.6$).
- Figure 1d: The first segment's curvature is within limits ($c_1 = 0.24$), the 2nd robot brakes itself to attain cruise speed. Second segment's curvature also enters within limits ($c_2 = 0.28$), therefore the 3th robot starts advancing at cruise speed.

- Figure 1e: Second segment raises again above 0.30 ($c_2 = 0.32$), the 3th robot stops. The 2nd robot keeps advancing at cruise speed ($c_1 = 0.2$).
- Figure 1f: Second segment falls below limits ($c_2 = 0.15$), the 3th robot accelerates to fast speed. The 2nd robot keeps advancing at cruise speed ($c_1 = 0.27$).

Some videos can be found on our web site: <http://www.ehu.es/ccwintco/index.php/DPI2006-15346-C03-03-Resultados-videos-control-centralizado>

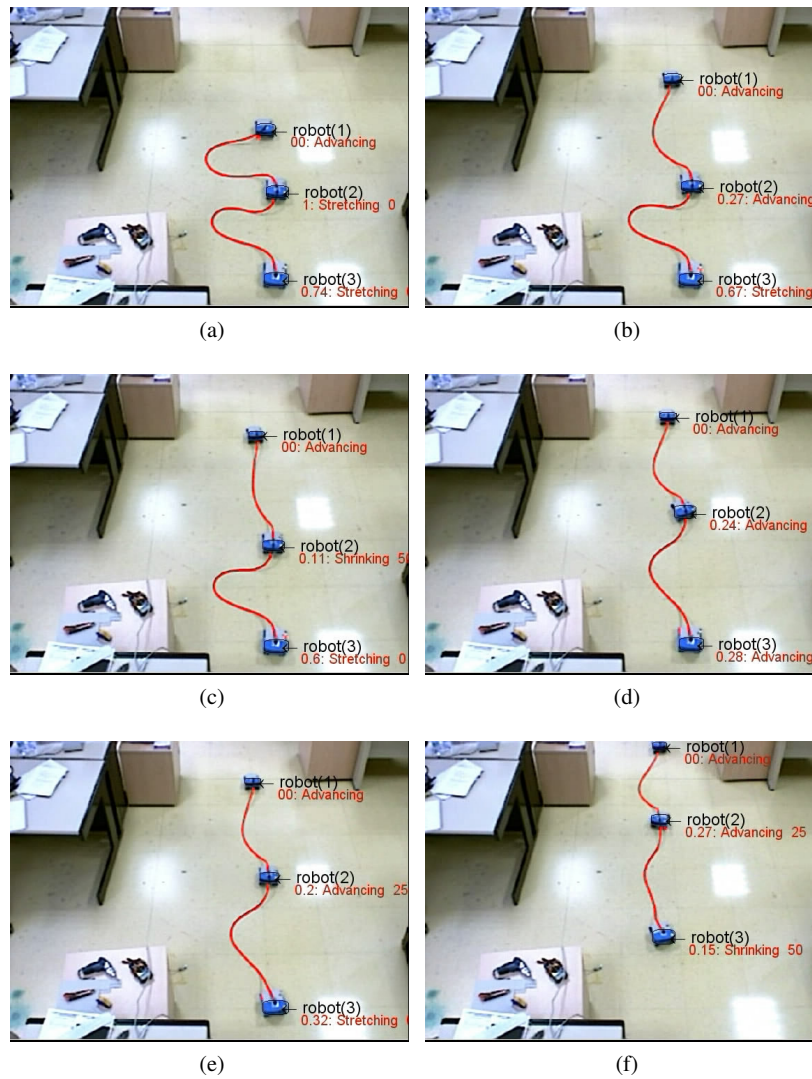


Fig. 1: Frames extracted from the video of an example realization of the hose transportation task.

4 Conclusions and discussion

We have realized the physical proof-of-concept of the vision based control of a robotic MAS, in the form of a Linked MCRS, performing the transportation of a hose-like object. The experiment of physical realization of the hose transportation task has served also to demonstrate some specific traits of the hose-robot Linked MCRS. For such a simple behavior as the “follow the leader”, we have observed that the hose-like passive element introduces dynamic interaction problems, as the hose may be an obstacle for the robots, can drag them or provoke dragging between them and its weight and rigidity impose motion constraints to the robots to follow a desired path.

The hose-like element introduces new perception and measurement needs: we need to observe (segment) the hose, and to compute some measure of its state that allows to build a system of rules that determines the agents’ behavior as a function of this state. The hose imposes also an ordering on the motion of the robots, both spatial and temporal. The perception of the hose and the fine tuning of the effects of its state are problems not shared by other MCRS paradigms. The experiment realization has been a success in the sense of demonstrating the inherent features of Linked MCRS and their needs.

The long term objective is the realization of a fully distributed control for a robotic MAS performing the deployment and transportation of a hose in a dynamic environment. However we need to define a collection of tasks that gradually approaches this goal. We are currently working on this and on the physical realization of the robot-hose system with other robotic modules.

References

1. Y. Uny Cao, Alex S. Fukunaga, and Andrew Kahng. Cooperative mobile robotics: Antecedents and directions. *Autonomous Robots*, 4(1):7–27, March 1997.
2. Gregory Dudek, Michael R. M. Jenkin, Evangelos Miliotis, and David Wilkes. A taxonomy for multi-agent robotics. *Autonomous Robots*, 3(4):375–397, December 1996.
3. Richard J. Duro, Manuel Graña, and Javier de Lope. On the potential contributions of hybrid intelligent approaches to multicomponent robotic system development. *Information Sciences*. Accepted for publication.
4. Zelmar Echegoyen. *Contributions to Visual Servoing for Legged and Linked Multicomponent Robots*. PhD thesis, University of the Basque Country, 2009.
5. Zelmar Echegoyen, Alicia D’Anjou, Ivan Villaverde, and Manuel Graña. Towards the adaptive control of a multirobot system for an elastic hose. In Vassilis Kaburlasos, Uta Priss, and Manuel Graña, editors, *Advances in Neuro-Information Processing*, volume 5506/2009 of *Lecture Notes in Computer Science*, pages 1045–1052. Springer, 2009. ISBN 978-80-244-2112-4.
6. A. Farinelli, L. Iocchi, and D. Nardi. Multirobot systems: a classification focused on coordination. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on*, 34(5):2015–2028, October 2004.
7. Jacques Ferber. *Multi-agent systems: an introduction to distributed artificial intelligence*. Addison-Wesley, 1999.
8. Jose Manuel Lopez Guede, Manuel Graña, Ekaitz Zulueta, and Oscar Barambones. Economical implementation of control loops for multi-robot systems. In *Advances in Neuro-Information Processing*, volume 5506/2009 of *Lecture Notes in Computer Science*, pages 1053–1059. Springer, 2009.
9. Steven A. Shafer. Using color to separate reflection components. *Color Research and Applications*, 10:43–51, April 1984.
10. R. T. Tan and K. Ikeuchi. Separating reflection components of textured surfaces using a single image. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 27(2):178–193, February 2005.