Interactive Bubble Robots for Art:Movement Sequences Learning through Mirror Neurons

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Abstract: This research begins from the study of the cooperative behavior of inspection robots by combining the concept of art and complex system. The role of chaotic synchronization in the generation of the kinematics trajectory shows the discovering of new aesthetic features of the motion in mechanical control systems. Also the research takes inspiration from the study of the applications on robotics of Mirror Neurons as principles of imitation and learning of movement.

Keywords: Mirror neurons, action recognition, robotics, chaos, art, strange attractors.

1. INTRODUCTION

In recent years many scientists explored the possibility of creating interactive installations in order to study the deep relationships between the spectator and the artwork [Shanken (2002)]. The generation of shapes and patterns, in fact, is an emergent phenomenon and these concepts are gaining increasing interest [Bucolo et al. (2008)]. The use of public interactive installation in the engineering-entertainment area suggests the idea of establishing new ways and new methods to create art with the intent of satisfying the need of bringing new technologies to users [Popper (1993),Popper (2007)]. This research takes inspiration from the study of the interactive processes between human and robot defined as HRI (Human and Robot Interaction) and from the study of Mirror Neurons applications in robotics in order to design structures able to imitate and learn from movement sequences [Gallese et al. (1996)],[Borenstein et al. (2005)]. The target of the work is to show artistic emergent spatial patterns, generated by clusters of robots called "Interactive Bubble Robots for Art", reflecting the interactions between human and robot and the learning processes through imitation and through the process of understanding the behaviour of others [Nagai (2005)], [Erlhagen et al. (2006)].
Moreover, the idea of applying on entertainment robotics the results of nonlinear dynamics theory for the generation of strange attractors or patterns has been recently investigated. The idea was connected with previous studies on groups of robots working together, with different skills. In particular, the use of dynamical chaos, instead of classic random algorithms, to drive robots in a given arena, and the development of chaotic laws to manage robots have been investigated in [Camerano et al. (2008)]. This paper illustrates the basic concepts of mirror neurons and of the "Mind-Reading" Theory [Gallese (2001)]. Furthermore, the discovery of the mechanism used in neurophysiology for action recognition in monkeys and human will be briefly introduced in Section 2. Relationships between science, technology and art through chaos, robotics, and mirror neurons, will be illustrated in Section 3. In Section 4 the mechanical structure of the used robots will be presented as well as robot operating conditions; moreover, the control laws will be described. In Section 5 experiments realized through the Interactive Bubble Robots for Art will be presented and the application of Mirror Neurons concept to robotics evaluated. In the concluding Section 6 the future trends on the use of coordinated robots to discover aesthetic motion trajectories will be emphasized.

2. MIRROR NEURONS AND MIND-READING THEORY

Imitation and the understanding of the behaviors of others is an important topic of strong interest for several disciplines including neurophysiology and neuroscience [Iacoboni et al. (2007)] and recently it also attracted the interest of engineers and researchers for applications in robotics [Oztop et al. (2006)]. A possible approach to this fascinating topic is the approach of the "Mind-Reading" Theory and the mechanisms of the Mirror Neurons [Demiris (1999)]. Mirror neurons are active cells in the macaque brain, located in the ventral premotor Area (Area F5) of their brain: the study of these neurons revealed that they have motor and visual properties, they are cells emitting information when the monkey performs a specific action and when it observes someone else performing similar actions. The discovery of mirror neurons in monkeys and in humans has been defined as the most important discovery of the last decade in all the neuroscience. Mirror neurons represent today the key element in the understanding of phenomena like imitation, evolution of language, autism, knowledge of the behaviour of others. The study reveals that Area F5 of macaque brain has a direct projection to the upper cervical segments of the spinal cord, and the stimulation of this area evokes in the motor cortex mouth and hand movements and also actions such as grasping, manipulating and holding [Urgesi et al. (2006)]. The "Mirror Neurons Theory" distinguishes two different kinds of visual neurons: the "Canonical Neurons" that are activated during observation of objects and the "Mirror Neurons" that are activated when the monkey observes another one performing an action [Rizzolatti and Craighero (2004)]. This mechanism in the brain of the monkey is able to show the congruence between the observed and the executed action. The Simulation Theory of Mind-Reading [Gallese and Goldman (1998)] requires two different kinds of simulation: a "Predictive" simulation that gives an action under the hypothesis that the observer has the same final goal of the observed one, and a "Retrodictive" simulation which extracts, similar mental states producing an observed action. Motor control theory studied by [Wolpert et al. (2001)] requires two different kinds of motor commands. They postulate an "Action-to-Goal" model that receives information about an action and then makes a goal for it, while in the "Goal-to-Action" model one system generates a specific action for the goal that is shown as input. At the same time in [Wolpert et al. (2001)] a "Forward Model" is assumed that represents a "predictor" receiving a replica of the motor command and generating the expected action for it, instead of the "Inverse Model" that represents a "controller" and produces motor commands that are specific to realize a desired final goal [Erlhagen et al. (2006)].

3. CHAOS, ROBOTICS AND MIRROR NEURONS: SCIENCE, TECHNOLOGY AND ART

The aim of the research including cooperative robots, strange attractors synchronization, led trajectories analysis, is to complete in some features the ingredients mentioned in "From Technological To Visual Art" [Popper (2007)], in order to conceive robots to be integrated in virtual arts where the key element is the spectator interaction and participation [Adams (1995)]. The intersection between technology and art is an increasing trend in the last 20 years [Moura et al. (2005)]. Science, technology and art have been connected since the 60's, when scientists, artists, and inventors begun to cooperate and use electronic tools to create art [Ascott (1964)]. The literature is full with examples of artists applying mathematics, robotic technology, and computing to the creation of art [Edmonds et al. (2004)]. The generation of strange attractors and emergent shapes and patterns has been widely faced in the last years [Chua (1997)],[Arena et al. (2005)]. The wide variety of patterns based on strange attractors achieved an impressive aesthetic level such that more people worked in order to emphasize in art the impressive features of strange attractors considering chaos as a bridge between art and science [Pickover et al. (2001)]. For example, in 2006 at the Zendai Museum of Modern Art an impressive exhibition entitled "Strange attractors: charms between art and science" has been organized. In this context the important aspect of our paper is therefore to relate emergent patterns, robots and arts [Chandler (2004)]. Lots of engineers and researchers today design robots with special neural-network-brain and special mechanisms able to paint, to play music and dance [Singer et al. (2004)], they create Art through Technology, they realize interactive shows and interactive art-installations, they discover a new Art through nature laws and chaotic laws [Flake (2002)], and also they discover Art trough science. Other researchers study the connection and the relationships between Mirror Neurons and the imitation of gestures, relationships between Mirror Neurons, emotion and esthetic experience [Freedberg et al. (2007)]. The study of Mirror Neurons offers the possibility of a clearer understanding of the relationships between responses to the perception of movement within sculpture, painting, architecture and dance. These researches reveal that Mirror Neurons have important implications not only in the process of creation of art by the artist but also "Mirror system integrates observed action of others with an individual's personal motor artistic repertoire and suggests that human brain understands action by motor simulation" [Cross (2006)]. Mirror Neurons have several applications in the modelling of auditory-motor integration, in applications of interaction and imitation between human and robots [Spaak et al. (2008)]. Starting from the study of this literature-background our research proposes an interaction between two identical Bubble Robots through the mechanism of Mirror Neurons. At the same time we analyse "the beauty of the chaotic patterns" [Aks et al. (1996)] generated by the dynamics and the trajectories described by Bubble Robots.

4. CHAOTIC CONTROL LAW

The robot realized in this research makes use of a differential drive motor configuration: the description of robot kinematics in terms of a differential drive system should be considered as an higher level abstraction. In the differential drive model, robot motion depends on the velocity of its center point that is the midpoint of the axle. This velocity is the average between the velocities of the two wheels. The steering depends on the difference between the mentioned velocities. Let us indicate with x, y, θ, the position and orientation of the robot with respect to a fixed system of cartesian coordinates and with b the length of the axle, i.e. the distance between the two wheels. The differential drive model can be described by the following equations [Camerano et al. (2008)]:

$$\begin{aligned} \frac{d\theta}{dt} &= \frac{v_R - v_L}{b} \\ \frac{dx}{dt} &= \frac{v_R + v_L}{2} \cdot cos\left(\theta\left(t\right)\right) \\ \frac{dy}{dt} &= \frac{v_R + v_L}{2} \cdot sin\left(\theta\left(t\right)\right) \end{aligned} \quad (1)$$

The robot is driven by a control law which specifies $v_R(t)$ and $v_L(t)$ at each time instant. In particular a logistic map is used whose equation is:

$$z_{k+1} = az_k(1 - z_k) \quad (2)$$

and, given z_k, we have $v_R(t)$ and $v_L(t)$ for $t_k \leq t < t_{k+1}$ by the algorithm described below. A new value of the