Welcome to the Jungle - Robots Entering the Realm of Animals

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Abstract
In this paper we summarize different experiments and projects that focus on animal-robot interaction. Based on the given examples, a general classification method is derived. A further class of applications in the field of animal-robot interaction is added and illustratively outlined.

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Robot, animal, interaction, behavior, ethology, control, communication, emotional expression

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Introduction
Robots are the vehicles that allow artificial intelligences to enter our reality. However, it is not only the realm of their creators that robots encounter, but also of all other beings that we share this world with. A multitude of experiments has already shown that the interaction between animals and robots offers a great potential in regards to animal studies, the control of animals, and even the active use of robot technology by animals. In the next three chapters a selection of such experiments is presented. We especially focus on the kinds of interactions in the different approaches as well as on their (future) purposes. In order to provide an easy description of applications in the fields of animal-robot interaction, a simple, task-oriented classification method is suggested. Finally, two promising animal-robot applications are presented. One would help to improve the usability of robots for humans, the other one might help to improve the capabilities of animals.

Ethorobotics
Many experiments have been conducted in which robots are used to study animal behavior, which is generally called *ethology*. Hence, it has been suggested to call the branch of robotics that serves this purpose *ethorobotics* [1].

The easiest strategy in order to study an animal is its supervision over a long period of time. In cases of vast or inaccessible observation areas, a surveillance camera (a so-called *critter cam*) can be mounted on the head or on the back of an animal to record the desired information. Even the critter cam is not sufficient for the research project of David Scheel and his group [10]. In order to track and film underwater creatures, such as giant octopus, they are developing a small robot, called *Shadow*, which is equipped with a video camera and is intelligent enough to follow its objective, and even to wait for the animal to re-appear after hiding beneath a stone for a long while. Independently from Scheel's group, fish-like robots are developed that are supposed to facilitate these kinds of sea-world expeditions [3].

Another common approach in ethology is to display various signals, for example from an audio or a visual source, and then create behavioral models for the animals by evaluation of their reactions. However, this method imposes several limitations on the researchers. There must be profound knowledge about how the animals perceive the signal from the used information source, considering for example flat, two-dimensional projections on television screens, instead of real (three-dimensional) communication partners. Second, the recreation of life-like situations in a laboratory can be very difficult or even impossible. Also, communication with the animals relies on a dynamic feedback from the signal source, which is often not easy to realize. There is a famous example in which all these problems have been solved by using a robot bee: The robot communicates a food location by performing the dance of a worker bee inside a hive [8]. Even though this experiment of the early 1990s is highly contended nowadays (see [13]), it has inspired numerous projects, in which animals unveiled hints on their behavior while interacting with robots [4]. A systematic confrontation between a puppy robot (called AIBO) with a real dog is a good example to show the potential, but also the difficulties that can occur when applying the outlined method [5]. The experiment allows the comparison between reactions of dogs to a remotely controlled car, to an AIBO robot, to an AIBO robot that was completely covered with dog-scented fur and to a real puppy. The real puppy and the furry robot have been treated similarly in a neutral situation. However, the interest for the robot quickly lessened after the routinely performed snooping by the dog. Also, the dogs kept a rather far distance to the robot, which might be interpreted as an indicator of fear. If the dog was approached while it was feeding, only the real puppy caused a mature dog to growl frequently – the robot might have not be seen as a threat. Juvenile dogs, however, growled much more often and sometimes even attacked the furry robot. Kubinyi et al. conclude that for the successful mimicry of a dog, a robot has to send more than only visual signals (especially olfactory signals) and has to show fast-responding and complex interactive behavior.

Animal Control

A very complex experiment to gather information about cockroaches is conducted by the LEURRE project, which is sponsored by the European Union. A good overview of the project is given in [2]. In addition to the perfection of the behavioral model of the cockroaches (*Periplaneta americana*), the project has a far more ambitious goal: The control of a society of cockroaches by infiltration with several specially designed robots called *InsBots*. Although, there are still issues with the disguise of robots as congeners, the researchers assume that they will succeed in influencing the emergent behavior of the society. Since the probability that a cockroach takes shelter in a certain area highly depends on the number of mates that have already gathered at that location, their first designated goal is to use InsBots to lure the cockroaches to a specific location. The same kind of goal is shared by another project, called the *Robot Sheepdog Project*, where the objective is to gather a flock of ducks near a pre-defined location [12]. However, there is a great difference between the Leurre and the Robot Sheepdog Project: In the first case the scientists try to integrate their robots into the animal society and then manipulate its overall behavior. In the latter case, the researchers make use of the fact that the ducks are scared by the distinct display of the (non-disguised) robot. The resulting fleeing urge of the ducks in combination with a simple underlying model of flocking behavior makes the movement of the ducks predictable. Hence, the robot can easily drive the ducks to a specific location.

As we have shown, there are approaches where animals are controlled by plain robots or by animal-like robots. Sometimes, it even becomes necessary to design robots akin to human beings. For example, a Swiss company was instructed to develop robots that substitute young children that were used as jockeys for traditional camel races in Qatar [6]. During the race, the robot is remotely controlled from a sport utility vehicle that drives next to the camel. The robots provide a wide repertoire of actions. Its whip can be used to strike at different locations and with an adjustable level of intensity, or just to flick next to the ear of the camel. Also, the robot can slacken or tighten the reins. The remote control screen for the human-robot interaction provides only the following information: The speed and heart rate of the camel and the remaining battery life of the robot. From the first reports it may be derived that the sequence of human-robot-animal interaction works perfectly fine, whereas it should be pointed out that the camels would only accept robots with a “natural” human face color and not the original ones that were completely white above the trunk.

Animals in Charge

Animals do not necessarily have to inherit the role of the supervised or manipulated object when they become part of a project that involves some kind of animal-robot interaction. For instance, scientists have designed and implemented robots that take care of fish [7]. One of the two developed robots transports and supplies food, after the fish has triggered a sensor that is installed inside a fish tank. The other robot is informed by a surveillance system about when and where to clean the pond. These robots have been implemented for large fish farms, with the potential to ease both, the lives of the owners of the facility and the lives of the fish.

However, the range of actions that can be expected from an animal to make use of robot technology is not generally limited to triggering a single sensor or button. If a proper interface is provided, any reproducible action or action sequence of an animal can basically be used to command a robot. Experiments conducted by Nicolelis et al. show that it is possible to enable a monkey to steer a robot arm in real-time [8]. In order to achieve this, the neural activity in the motor cortex of the monkey is first measured, then transformed and finally fed to the robotic arm. Although Nicolelis et al.

point out that their experiments are of special interest for medical treatment of human beings, they, at the same time, witness the incredibly great potential of animals controlling robot technology.

Classification of Animal-Robot Applications

The previous chapters give a quick overview of various projects that involve animal-robot interaction. There is the great approach of ethorobotics that opens new dimensions in gaining insights in the behavior, the communication and particular parts of the life cycles of animals. There are tasks, such as herding or riding camels that can be performed by robots, nowadays. Robots enable us to infiltrate, influence and maybe even control hives and cockroach societies. Finally, examples have been shown in which animals were allowed to be in charge of robots (even if only for the sake of medical research).

These examples have already shown that there is a vast number of different applications with animal-robot interaction components. Hence, we suggest the consideration of the following five questions, in order to provide a quick classification of such an application.

- *Who (or what) are the involved parties?*
- *Who influences whom?*
- *How does the influence take place?*
- *What is the impact of the influence?*
- *What is the goal of the interaction?*

In the case of the camel riding robots the classification would be as follows. There are three parties involved in the interaction: A human, the robot and the camel, with a chain of influence in the given order. The human being remote controls the actions of the robot and the camel reacts on these actions. The remotely triggered actions of the robot, namely using its whip or the reins, steer the camel. The goal of the interaction is to drive the camel as fast as possible on course.

Perspectives of Animal-Robot Interaction

With an overview of animal-robot applications in mind and a simple classification scheme at hand, it is easy to think of future developments in this field of science.

The ancient dream of a simple, but clearly defined way of communication between animals and humans might become true, if we increase our knowledge of animals by the means of ethorobotics and start using artificial congeners to talk to the animals in a “language” which they can naturally understand.

A success of the LEURRE project in taking influence on the behavior of cockroach societies would open the door for humanity to a completely new “tool”. Insect swarms have a reputation as incredibly powerful entities in nature. If they were controlled in a very effective fashion, they might become extremely useful and play roles in the engineering or the architectural projects of the future.

On the other hand, allowing animals to control robots or by providing them with robotic tools, as it has happened in the experiments of Nicolelis et al., could improve their mental abilities of the animals, so that the animals themselves might become even more useful to us than they already are. We outline this idea of learning by animal-robot interaction more in detail in the next chapter, for we are convinced that it has a great potential for the evolution of the behavior and the mental capabilities of both, animals and robots.

Learning and Teaching in Animal-Robot Interaction

Physical properties of animals have often served as inspiration for engineers when challenges arose concerning the specific design of robots (for instance the optimization of underwater movement, see [3]). The resulting robots are also called *biomimetic robots*. Nowadays, there is still a great potential for robot design by mimicking animals – not only in regards to the blueprints of robots, but also in terms of their behavior. Domestic pets, especially the dog as their most prominent representative, have co-evolved with humans for a long time [11]. Hence, an animal-like behavior of robots might result in both, an effective and an efficient cooperation between humans and robots: Effective, since we are naturally familiar with the behavior of domestic pets. We have learned to use their capabilities in miscellaneous situations and we know about their physical abilities and limitations. The interaction between humans and animal-like robots would also be efficient, since the communication between humans and animals heavily relies on very clear audio and visual signals that might be easily interpreted by robots. The directness of the signals is only but one feature of the ways of communication between humans and animals. In order to achieve animal behavior of robots, we propose a scenario where robots are actually trained by animals.

The acceptance of the furred robotic dog, mentioned in Chapter *Ethorobotics*, by normal dogs depends most likely on the familiarization of the two (see again [5]). Therefore, the rejection of robot dogs by real dogs could probably be lessened if the first contact was established in an earlier stage of the life of a dog. Hence, we suggest bringing the robot and a very young puppy together just to be with each other. The puppy would get used to the robot, and the robot could, for instance, try to imitate the movements of the puppy and learn them at the same time. Later on, when the robot is equipped with a considerable assortment of basic behaviors, it might actually become interesting for the dog to play with the robot. The goal of the interaction at this point in time could still include learning animal behavior, or the interaction might take place for reasons of ethology only.

Of course, robots could also be used to teach animals. It is a very time-consuming task to teach animals what we expect from them in different situations. Consider, for example, the immense efforts that are necessary to equip a German shepherd with the repertoire of actions that enables it to support police forces or even to guide a blind person. Since training an animal is usually a rather repetitive and straightforward process, a robot could be designed to perform this task. In accordance to the classification system that we have suggested, such an interaction can be described as follows. A training robot in disguise of a human being and a German shepherd are present. The training robot holds its hand in a specific way and thereby signals its expectations from the dog. When the dog behaves as desired, the robot provides a reward, for example in the form of small snack. Then the robot displays its hand in a different way and the process is repeated.

Summary

The field of animal-robot interactions offers as many possibilities as the field of human-robot interactions: There do not seem to be any limits. Plenty of promising approaches are being developed, learning and teaching in animal-robot interaction could become one of them.

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