INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Flowers

Flowing Epigenetic Robots and Systems : Developmental and Social Robotics

Bordeaux - Sud-Ouest

Theme : Robotics

Activity Report

2009

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2. Overall Objectives

2.1. Introduction

Can a robot learn like a child? Can it learn new skills and new knowledge in an unknown and changing environment? How can it discover its body and its relationships with the physical and social environment? How can its cognitive capacities continuously develop without the intervention of an engineer? What can it learn through natural social interactions with humans?

These are the questions that are investigated in the FLOWERS research team at INRIA Bordeaux Sud-Ouest. Rather than trying to imitate the intelligence of adult humans like in the field of Artificial Intelligence, we believe that trying to reconstruct the processes of development of the child's mind will allow for more adaptive, more robust and more versatile machines. This approach is called developmental robotics, or epigenetic robotics, and imports concepts and theories from developmental psychology. As most of these theories are not formalized, this implies a crucial computational modeling activity, which in return provides means to assess the internal coherence of theories and sketch new hypothesis about the development of the human child's sensorimotor and cognitive abilities.

Among the developmental principles that characterize human infants and can be used in developmental robots, FLOWERS focuses on the following three principles:

- **Exploration is progressive.** The space of skills that can be learnt in real world sensorimotor spaces is so large and complicated that not everything can be learnt at the same time. Simple skills are learnt first, and only when they are mastered, new skills of progressively increasing difficulty become the behavioural focus;
- **Internal representations are (partially) not innate but learnt and adaptive.** For example, the body map, the distinction self/non-self and the concept of "object" are discovered through experience with initially uninterpreted sensors and actuators;
- **Exploration can be self-guided and/or socially guided.** On the one hand, internal and intrinsic motivation systems regulate and organize spontaneous exploration; on the other hand, exploration can be guided through social learning and interaction with caretakers.

2.1.1. Research axis

The work of FLOWERS is organized around the following three axis:

- **Intrinsically motivated exploration and learning:** intrinsic motivation are mechanisms that have been identified by developmental psychologists to explain important forms of spontaneous exploration and curiosity. In FLOWERS, we try to develop computational intrinsic motivation systems and test them on robots, allowing to regulate the growth of complexity in exploratory behaviours. These mechanisms are also studied as active learning mechanisms, allowing to learn efficiently in large inhomogeneous sensorimotor spaces;
- **Natural and intuitive social learning:** FLOWERS develops interaction frameworks and learning mechanisms allowing non-engineer humans to teach a robot naturally. This involves two sub-themes: 1) techniques allowing for natural and intuitive human-robot interaction, including simple ergonomic interfaces for establishing joint attention; 2) learning mechanisms that allow the robot to use the guidance hints provided by the human to teach new skills;
- **Discovering and abstracting the structure of sets of uninterpreted sensors and motors:** FLOWERS studies mechanisms that allow a robot to infer structural information out of sets of sensorimotor channels whose semantics is unknown, such as for example the topology of the body and the sensorimotor contingencies (propriocetive, visual and acoustic).

These three research axis are applied to the learning of two kinds of skills: basic sensorimotor skills and basic socio-linguistic skills (bootstrapping and learning of the first words).

2.2. Highlights of the year

Pierre-Yves Oudeyer received an ERC Starting Grant for the project EXPLORERS associated with a 1.5 million euros funding.

Olivier Ly lead the building of the Acrhoban humanoid robot platform, the first french humanoid platform with a semi-passive vertebral column and that allows soft physical interactions with humans. The platform was demonstrated in the international robotics exhibition “Fututo Remoto” in the Science Museum of Naples, Italy.

A project of start-up company involving Olivier Ly and Pierre-Yves Oudeyer was elaborated, focused on robotics engineering, and was laureate of the OSEO competition in the “emergence” category.

Jérome Béchu, Olivier Ly and Pierre-Yves Oudeyer built the FLOWERS FIELDS robotics system, which is an installation composed of social robotic lamps that are sensitive to the surrounding human environment. It was also demonstrated at the “Futuro Remoto” exhibition.

Thomas Schatz and Pierre-Yves Oudeyer obtained the best student paper award at the IEEE International Conference on Development and Learning.

Pierre-Yves Oudeyer was program co-chair of the 9th International Conference on Epigenetic Robotics.

3. Scientific Foundations

3.1. Scientific Foundations

Research in artificial intelligence, machine learning and pattern recognition has produced a tremendous amount of results and concepts in the last decades. A blooming number of learning paradigms - supervised, unsupervised, reinforcement, active, associative, symbolic, connectionist, situated, hybrid, distributed learning... - nourished the elaboration of highly sophisticated algorithms for tasks such as visual object recognition, speech recognition, robot walking, grasping or navigation, the prediction of stock prices, the evaluation of risk for insurances, adaptive data routing on the internet, etc... Yet, we are still very far from being able to build machines capable of adapting to the physical and social environment with the flexibility, robustness, and versatility of a one-year-old human child.

Indeed, one striking characteristic of human children is the nearly open-ended diversity of the skills they learn. They not only can improve existing skills, but also continuously learn new ones. If evolution certainly provided them with specific pre-wiring for certain activities such as feeding or visual object tracking, evidence shows that there are also numerous skills that they learn smoothly but could not be "anticipated" by biological evolution, such as for example learning to drive a tricycle, using an electronic piano toy or using a video game joystick. On the contrary, existing learning machines, and robots in particular, are typically only able to learn a single pre-specified task or a single kind of skill. Once this task is learnt, for example walking with two legs, learning is over. If one wants the robot to learn a second task, for example grasping objects in its visual field, then an engineer needs to re-program manually its learning structures: traditional approaches to task-specific machine/robot learning typically include engineer choices of the relevant sensorimotor channels, specific design of the reward function, choices about when learning begins and ends, and what learning algorithms and associated parameters shall be optimized.

As can be seen, this makes a lot of important choices from the engineer, and one could hardly use the term "autonomous" learning. On the contrary, human children do not learn following anything looking like that process, at least during their very first years. Babies develop and explore the world by themselves, focusing their interest on various activities driven both by internal motives and social guidance from adults who only have a folk understanding of their brains. Adults provide learning opportunities and scaffolding, but eventually young babies always decide for themselves what activity to practice or not. Specific tasks are rarely imposed to them. Yet, they steadily discover and learn how to use their body as well as its relationships with the physical and social environment. Also, the spectrum of skills that they learn continuously expands in an organized manner: they undergo a developmental trajectory in which simple skills are learnt first, and skills of progressively increasing complexity are subsequently learnt.

A grand challenge is thus to be able to build robotic machines that possess this capability to discover, adapt and develop continuously new know-how and new knowledge in unknown and changing environments, like human children. In 1950, Turing wrote that the child's brain would show us the way to intelligence: "Instead of trying to produce a program to simulate the adult mind, why not rather try to produce one which simulates the child's" [55]. Maybe, in opposition to work in the field of Artificial Intelligence who has focused on mechanisms trying to match the capabilities of "intelligent" human adults such as chess playing or natural language dialogue [38], it is time to take the advice of Turing seriously. This is what a new field, called developmental (or epigenetic) robotics, is trying to achieve [43] [57]. The approach of developmental robotics consists in importing and implementing concepts and mechanisms from developmental psychology [45], cognitive linguistics [30], and developmental cognitive neuroscience [41] where there has been a considerable amount of research and theories to understand and explain how children learn and develop. A number of general principles are underlying this research agenda: embodiment [26][17], grounding [36], situatedness [19], self-organization [53][18], enaction [56], and incremental learning [28].

Among the many issues and challenges of developmental robotics, two of them are of paramount importance: exploration mechanisms and mechanisms for abstracting and making sense of initially unknown sensorimotor channels. Indeed, the typical space of sensorimotor skills that can be encountered and learnt by a developmental robot, as those encountered by human infants, is immensely vast and inhomogeneous. With a sufficiently rich environment and multimodal set of sensors and effectors, the space of possible sensorimotor activities is simply too large to be explored exhaustively in any robot's life time: it is impossible to learn all possible skills. Moreover, some skills are very basic to learn, some other very complicated, and many of them require the mastery of others in order to be learnt. For example, learning to manipulate a piano toy requires first to know how to move one's hand to reach the piano and how to touch specific parts of the toy with the fingers. And knowing how to move the hand might require to know how to track it visually.

Exploring such a space of skills randomly is bound to fail or result at best on very inefficient learning [1]. Thus, exploration needs to be organized and guided. The approach of epigenetic robotics is to take inspiration from the mechanisms that allow human infants to be progressively guided, i.e. to develop. There are two broad classes of guiding mechanisms which control exploration:

Psychologists have identified two broad classes of guiding mechanisms which control exploration:

1. **internal guiding mechanisms,** and in particular intrinsic motivation, responsible of spontaneous exploration and curiosity in humans, which is one of the central mechanisms investigated in FLOWERS, and technically amounts to achieve on-line active self-regulation of the growth of complexity in learning situations;
2. **social learning and guidance,** which exists in many different forms like emotional reinforcement or imitation, some of which being also investigated in FLOWERS;

3.1.1. Internal guiding mechanisms.

In infant development, one observes a progressive increase of the complexity of activities with an associated progressive increase of capabilities [45], children do not learn everything at one time: for example, they first learn to roll over, then to crawl and sit, and only when these skills are operational, they begin to learn how to stand. Development is progressive and incremental, and this might be a crucial feature explaining the efficiency with which children explore and learn so fast. Taking inspiration from these observations, some roboticists and researchers in machine learning have argued that learning a given task could be made much easier for a robot if it followed a developmental sequence and "started simple" [20] [34]. However, in these experiments, the developmental sequence was crafted by hand: roboticists manually build simpler versions of a complex task and put the robot successively in versions of the task of increasing complexity. And when they wanted the robot to learn a new task, they had to design a novel reward function.

Thus, there is a need for mechanisms that allow the autonomous control and generation of the developmental trajectory. Psychologists have proposed that intrinsic motivations play a crucial role. Intrinsic motivations are mechanisms that push humans to explore activities or situations that have intermediate/optimal levels of novelty, cognitive dissonance, or challenge [23] [31] [33]. The role and structure of intrinsic motivation in humans have been made more precise thanks to recent discoveries in neuroscience showing the implication of dopaminergic circuits and in exploration behaviors and curiosity [32] [39] [51]. Based on this, a number of researchers have began in the past few years to build computational implementation of intrinsic motivation [1][2] [49] [22] [40] [44] [50]. While initial models were developed for simple simulated worlds, a current challenge is to manage to build intrinsic motivation systems that can efficiently drive exploratory behaviour in high-dimensional unprepared real world robotic sensorimotor spaces [2][1] [46][16] . Specific and complex problems are posed by real sensorimotor spaces, in particular due to the fact that they are deeply inhomogeneous: for example, some regions of the space are often unlearnable due to inherent stochasticity or difficulty. In such cases, heuristics based on the incentive to explore zones of maximal unpredictability or uncertainty, which are often used in the field of active learning [29] [37] typically lead to catastrophic results. In FLOWERS, we aim at developing intrinsically motivated exploration mechanisms that scale in those spaces.

3.1.2. Socially guided learning.

Social guidance is as important as intrinsic motivation in the cognitive development of human babies [45]. There is a vast literature on mechanisms allowing a human to socially guide a robot towards the learning of new sensorimotor skills [48]. Yet, many existing experiments focus either on only intrinsically motivated exploration [1] [22], or only socially guided exploration with imitation, demonstration or social cheering [27] [21]. Only few attempts, such as in [54], have been tried to couple intrinsic motivation and social learning. In FLOWERS, we work on developing advanced mechanisms for coupling social learning and state-of-the-art intrinsic motivation systems.

4. Application Domains

4.1. Application Domains

- **Personal robotics.** Many indicators show that the arrival of personal robots in homes and everyday life will be a major fact of the 21st century. These robots will range from purely entertainment or educative applications to social companions that many argue will be of crucial help in our aging society. For example, UNECE evaluates that the industry of entertainment, personal and service robotics will grow from $5.4Bn to $17.1Bn over 2008-2010. Yet, to realize this vision, important obstacles need to be overcome: these robots will have to evolve in unpredictable homes and learn new skills while interacting with non-engineer humans after they left factories, which is out of reach of current technology. In this context, the refoundation of intelligent systems that developmental robotics is exploring opens potentially novel horizons to solve these problems.

- **Video games.** In conjunction with entertainment robotics, a new kind of video games are developing in which the player must either take care of a digital creature (e.g. Neopets), or tame it (e.g. Nintendogs), or raise/accompany them (e.g. Sims). The challenges entailed by programming these creatures share many features with programming personal/entertainment robots. Hence, the video game industry is also a natural field of application for FLOWERS.

5. Software

5.1. UFlow

Participants: Jérome Béchu [correspondant], Pierre-Yves Oudeyer.

The UFlow Toolbox is a collection of various software modules for programming and scripting robot sensorimotor loops, aimed at allowing rapid prototyping in the FLOWERS team, and integrated in the URBI framework. URBI, developed by GOSTAI, supports the integration of heterogeneous robotic software modules. It uses a dynamic scripting language, wich manages parallel and event processing. Each module, called UObject, is written in C++.

We developed a new UObject for image acquisition on Windows : uCamera. This UObject uses the Microsoft Direct Show Library to easily access and retreive images. We can use one or more USB Camera (Currently we use 5 cameras on one PC).

An UObject, named uFaceDetection, uses the OpenCV Library to detect a face in a UImage.

Two UObjects manage a wiimote handle. One, named Wiimote and another one named uMacWiimote. The first one works on Windows while the other one works on Mac OS-X. Thanks to this UObject we can use wiimotes to manipulate robots.

To control a robot the Rovio robot, we developed an UObject uRovio. With this UObject we can send motion commands and retrieve images from the camera of the robot.

We developed an UObject dedicated to real-time sound processing and playing, named uSoundManager, and based on the fmod sound library.

Another UObject that we developped, named uLaser, allows to detect the position of a green laser pointer in real-time.

Finally, we currently update the UFlow Toolbox to URBI 2.0 (in progress).

5.2. RoboDrive

Participants: Pierre Rouanet [correspondant], Pierre-Yves Oudeyer.

RoboDrive is a software which allows mobility during the interaction with a robot. By looking at the screen, the user can see what the robot is looking at. He can also drive the robot by sketching on the touch-screen using the stylus. Then, specific gestures are used to draw the attention of the robot towards new objects, and the software allows the user to associate a name to these objects. Finally, the software allows the user to ask the robot to search and reach an object given its name/the word associated to it.

RoboDrive is based on an iPhone in order to use its multiple-interaction and multi-touch abilities and with the mid-term aim of making the software available to a larger audience. It is also providing interesting functionalities, such as driving the robot by litterally using the iPhone as a steering wheel (with the accelerometer). The interface has been designed based on iPhone API, making it much simpler and easy to use.

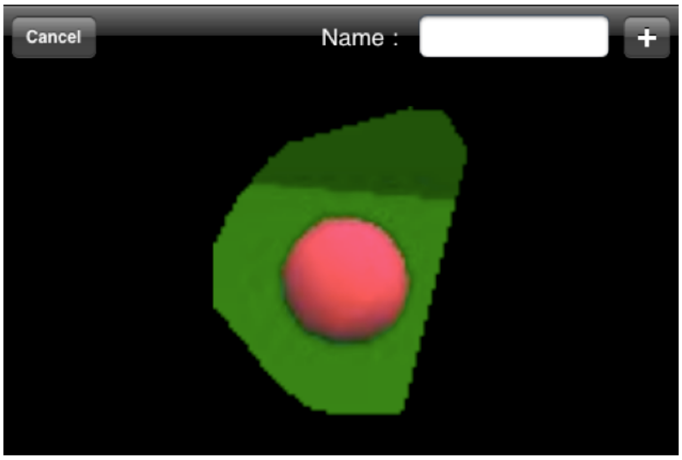

Figure 1. RoboDrive is an iPhone application that facilitates intuitive and robust human-robot teaching interactions

As mentioned above, this software allows users to associate names with new visual objects and so the interface has been designed to allow users and especially non-expert users to really provide the robot with good learning examples. Thus, when the user wants to teach a name for a new object, he first needs to encircle the object directly on the screen which provides a rough, but still very useful, segmentation of the image.

The software was also linked to a visual recognition and machine learning framework to allow a robust and fast recognition of any object. This framework is based on the bags of visual approach where lots of visual descriptors such as SIFT of SURF descriptor are extracted from an image or here only a portion of an image. These descriptors are then clustered into words and add to a vocabulary. Then we can use statistical methods based on the frequency of these words to recognized objects.

5.3. Wiimote-Laser Drive

Participants: Pierre Rouanet [correspondant], Pierre-Yves Oudeyer.

We also developed an other interface based on a Wiimote and a laser pointer which provide the same capacities as the RoboDrive software (see above) to the users. With this interface users can drive the robot with the Wiimote. While with the laser pointer users can draw the robot's attention, the laser spot is automatically tracked by the robot. A laser sound is played by the robot to notice users that the robot can see the light spot. Users can also encircle an object with the laser pointer to provide a new learning examples of this object.

The main difference between this interface and the iPhone based interface is that with the laser pointer users only know if the laser pointer is seen or not by the robot while with the iPhone interface users can monitor what the robot sees.

6. New Results

6.1. Evaluation of intrinsic motivation systems as active learning

Participants: Adrien Baranès, Pierre-Yves Oudeyer.

Figure 2. By using a Wiimote and a laser pointer we can easily interact with a robot and show it objects.

Developmental robots have a sharp need for mechanisms that may drive and self-organize the exploration of new skills, as well as identify and organize useful sub-spaces in its complex sensorimotor experiences. In psychology terms, this amount to trying to answer the question “What is interesting for a curious brain?”. Among the various trends of research which have approached this question, of particular interest is work on intrinsic motivation. Intrinsic motivations are mechanisms that guide curiosity-driven exploration, that were initially studied in psychology [58] [24] [33] and are now also being approached in neuroscience [32] [47] [52]. They have been proposed to be crucial for self-organizing developmental trajectories [1] as well as for guiding the learning of general and reusable skills (Barto et al., 2005). Experiments have been conducted in real-world robotic setups, such as in [1] where an intrinsic motivation system was shown to allow for the progressive discovery of skills of increasing complexity, such as reaching, biting and simple vocal imitation with and AIBO robot. In these experiments, the focus was on the study of how developmental stages could self-organize into a developmental trajectory without a direct pre-specification of these stages and their number. Yet, these algorithms can also be considered as “active learning” algorithms. This year, we have continued our work to show systematically that some of them also allow for very efficient learning in the unprepared spaces with the typical properties of those encountered by developmental robots, outperforming standard active learning heuristics. These results were partly published in [9][11][12][10].

6.2. Discovering acoustic words in unsegmented speech with no initial phonetic knowledge

Participants: Olivier Mangin, Pierre-Yves Oudeyer, David Filliat.

In developmental robotics, one aims at building robots capables of learning progressively and continuously new skills and new knowledge. One important challenge relates to language acquisition: How can a robot learn its first words and their associated meanings? This entails many interrelated problems. One of them is: How can a robot learn adequate acoustic/auditory representations of words? The technical challenges amounts to finding invariant features in sentences that contain words associated to concrete predefined meanings, but in which words are not initially segmented, and for which one does not possess detectors of high-level phonological representations such as phonemes (consonants and vowels). We have developped an approach to this problem which is based on a tranposition of the notion bags of features recently developped in computer vision. Bags of acoustic features are unstructured collections of features characterizing local properties of the signal, removing the relative timing information, and on which one can do massive but fast statistical computations. The transposition involved in particular to elaborate methods for building and searching fastly in dictionaries of short sound sequences using a dynamic time warping similarity measure. We have shown, using a large database provided by the ACORNS European consortium which focus on the very problem of word discovery in unsegmented speech with no initial phonetic knowledge, that the bag-of-word approach allowed very performance in this task that are comparable to the best methods that were identified by the ACORNS consortium. An article presenting these results is in preparation.

6.3. Intuitive gestural interfaces for human-robot language teaching

Participants: Pierre Rouanet, Pierre-Yves Oudeyer, David Filliat.

Social robots are drawing an increasing amount of interest both in scientific and economic communities [35] [25]. These robots should typically be able to interact naturally and intuitively with non-engineer humans, in the context of domestic services or entertainment. Yet, an important obstacle needs to be passed: providing robots with the capacity to adapt to novel and changing environments and tasks, in particular when interacting with non-engineer humans. One of the important difficulties is related to mutual perception and joint attention [42]. For example, when one has to teach a novel word or a new command to a robot, several challenges arise:

1. Attention drawing: when needed the human shall be able to draw the attention of the robot towards himself and towards the interaction (i.e. the robot should stop its activities and pay attention to the human);
2. Pointing: once the robot is concentrated on the interaction, the human should be able to show a part of the environment (typically an object) he is thinking of to the robot, typically by pointing, in order to establish a form of joint attention;
3. Naming: the human should be able to introduce a symbolic form that the robot can detect, register and recognize later on;

Given that users are not engineers, this should be realized both in a very intuitive and very robust manner in completely uncontrolled environments. This implies that relying on traditional vision techniques for detecting and interpreting natural human pointing gestures, and on traditional speech recognition techniques for spotting and recognizing (potentially new) words will not work. One way to achieve intuitive and robust attention drawing, pointing and naming is to develop simple artefacts that will serve as mediators between the man and the robot to enable natural communication, in much the same way as icon based artefacts were developed for leveraging natural linguistic communication between man and bonobos (see Kanzi and Savage-Rumbaugh).

This year, we have continued the development of such artefacts and associated interaction techniques, and built several complete systems as well as evaluated them in realistis settings with user studies. Two main human-robot interface systems are now functional: one is based on the use of an Iphone, and the other one is based on the use of a laser pointer coupled with a Wiimote controller. Furthermore, a complete system involving image processing with SIFT/SURF based local descriptors and visual object learning and recognition with a bag-of-words approach, was built and allowed us to conduct experiment assessing quantitatively how these interfaces allow efficient teaching of new visual objects to a robot. The papers [14][13][15] provide descriptions of these systems, as well as associated experiments which show that designing appropriate human-robot interfaces can allow to improve the efficiency of a learning system significantly more than what may expect from improving the machine learning algorithms or the computer vision algorithms.

6.4. Achroban: a humanoid robot platform with dynamic balancing and semi-passive vertebral column

Participants: Olivier Ly, Pierre-Yves Oudeyer.

The AcRhoban project deals with motor primitive learning for humanoid personal robotic. The robots in which we are interested have rich but a priori quite imprecise mechanical structure. This makes difficult to get analytic models for them. Instead of that our goal is to make them learn motor behaviours such as dynamic balancing, walking on non homogeneous surfaces, and even acrobatic moves. We propose an approach mixing the use of compliant motors with hybrid position/force control and learning. This should allow flexibility and reactiveness of moves, but also a better security and energy efficiency.

At the moment, the AcRhoban project follows the following directions :

A] Design and construction. The design study has been sufficiently advanced to allow the construction of a first prototype. This prototype includes 32 servo-motors allowing a control in position, but not only. Indeed, these servo-motors allow a fine control of the parameters of their position control low-level closed loop. In particular, one can control the compliance level of the mechanism, making it close to force control. In the design of AcRhoban structure, we focused on making the torso structure particularly rich, designing a simple spine with 5 degrees of freedom. The goal is to experiment the possibilities of balancing the robot using modifications of the shape of its torso.

B] Control and Learning. AcRhoban is controled by a software environment which has been developped within the Rhoban project from several years now. This environment allows to define robot motor behaviours on the basis of :

- piecewise-linear trajectories, designed by the user.
- PID (closed) reaction loops, implementing the reactions of the robot relatively to its environment (e.g. inertial sensors, but also control interfaces).

Moreover, a crucial point is the interaction between these two kinds of components of moves :

- trajectories can be used to define time variations of the closed loop parameters
- conversely (and even recursively), reaction loops can be used to regulate some parameters of the trajectories (amplitude, shift, etc.)

This system has been upgraded and is already used to design moves of AcRhoban, including " soft " compliant moves. So, the balancing system and the walking moves include programmed fixed trajectories, but also reactions to the environment of several natures : 1) reactions in joint positions (such as the pelvis position for balancing), 2) compliance level reactions (such as the feet compliance during the walk) 3) and finally direct reactions of the mechanical structure itself (being possible thanks to compliance and softness control).

Also, it must be noticed that the moves are embedded in the electronic board of the robot (including an ARM7 microcontroler). This has has been made possible thanks to significant embedded development. The goal is to make the robot completely autonomous (i.e. without wires).

This first prototype has been showed into several public demonstrations, involving collegues, but also large public show (futuro remoto 2009). This demonstrations emphasized a crucial aspect of the project : the use of soft joints allows the physical interaction with human. On top of the intrinsic interest of the public for such interaction, this open the field of experimentation of social learning including physical contact with humanoid robots on which we will focus in the next months.

6.5. FLOWERS FIELDS

Participants: Jérome Béchu, Olivier Ly, Pierre-Yves Oudeyer.

We designed, built, tested and demonstrated the FLOWERS FIELDS installation. This is a robotic installation that explores new forms and new functions of robotics. When we think of robots, we traditionally have in mind either humanoid robots that look like humans and are supposed to do similar things as humans, or industrial robotic arms which should work in factories. On the contrary, the future may come with unforeseen kinds of robots that may enter our everyday homes: for examples, as houses become themselves intelligent with domotics, we could imagine that furnitures themselves could become robots. Chairs, tables, televisions, or lamps may become robots. In FLOWERS FIELDS, five robotic lamps mounted on a table move like living entities, with their own moods and their own system of interaction. They can be thought to be in houses partly as aesthetic objects, and partly for their social presence. Indeed, not only their movements and sounds are life-like, but they are sensible to human presence and can become interested in looking and interacting with people through those movements and sounds. This installation was demonstrated at the "Futuro Remoto" international robotics exhibition in the Science Museum (Citta della Scienza) in Naples, Italy.

6.6. ILO-GMR: Incremental Local Online Gaussian Mixture Regression

Participants: Ming Li, Pierre-Yves Oudeyer, Adrien Baranès.

Many robot learning frameworks involve the use of regression algorithms. In such frameworks, the desirable properties of these algorithms are: 1) they should be able to work in high-dimensions; 2) They should be fast to train with millions of points; 2) Training should be incremental; 3) prediction should be fast; 4) They should be easy to manually tune when shifting from one problem to another. A number of techniques have become popular recently in robotics, such as Gaussian Processes, Locally Weighted Projection Regression (LWPR) and Gaussian Mixture Regression (GMR). But Gaussian Processes are often slow to train and not incremental, while LWPR is very difficult to tune because of its many parameters and GMR has no efficient incremental versions and need to be retrained globally when new training data is provided with a different input distribution. We have elaborated an incremental online local version of GMR, based on the only computation of local GMR with few components, which we proved to be as accurate as the other methods, robust to changes in the distribution of the training data, as well as very easy to tune. An extensive article describing the algorithm and its performances is in preparation.

7. Contracts and Grants with Industry

7.1. Contracts and Grants with Industry

Contacts have been established with various companies and joint project proposals are under review.

8. Other Grants and Activities

8.1. Other Grants and Activities

Pierre-Yves Oudeyer obtained an ERC Starting Grant for the EXPLORERS project, associated with a 1.5 million euros funding.

Pierre-Yves Oudeyer obtained a Région Aquitaine grant of 120 Keuros which allowed to recruit Thomas Cederborg as a PhD student.

9. Dissemination

9.1. Animation of the scientific community

9.1.1. Editorial boards

Pierre-Yves Oudeyer was program co-chair of the 9th International Conference on Epigenetic Robotics, Venice, Italy, and publicity co-chair of the 2009 IEEE International Conference on Development and Learning, Shangai, China.

Pierre-Yves Oudeyer has worked as Editor of the IEEE CIS AMD Newsletter, and member of the IEEE CIS Technical Committee on Autonomous Mental Development.

Pierre-Yves Oudeyer has worked as Associate Editor of: Frontiers in Neurorobotics (Frontiers Foundation) and International Journal of Social Robotics (Springer).

9.1.2. Program Committees

Pierre-Yves Oudeyer was a member of the following program committees: IEEE Congress on Evolutionary Computation (IEEE CEC'09), 2009; IEEE Alife 2009; IEEE International Conference on Development and Learning; 9th International Conference on Epigenetic Robotics.

9.1.3. Reviews

Pierre-Yves Oudeyer reviewed papers for the journals: Autonomous Robots, Adaptive Behavior, and for the conferences: IEEE Congress on Evolutionary Computation (IEEE CEC'09), 2009; IEEE Alife 2009; IEEE ICDL 2009; Epirob 2009.

9.1.4. Other

Pierre-Yves Oudeyer was expert for the European Commission for review and evaluations of several FP7 projects and calls.

9.2. Invited talks

(15th november 2009) The challenges of active learning and intrinsic motivation for learning motor control in high-dimensional robots, IMCLever workshop on Intrinsic Motivation and Socio-Emotional Development, Venice, Italy.

(14th november 2009) Why Language Acquisition and Intrinsic Motivation Should Go Hand in Hand, Joint Epirob'09-IMCLever workshop on Intrinsic Motivation and Socio-Emotional Development, Venice, Italy.

(6 june 2009) La robotique développementale, Séminaire Le Modèle et l'Algorithme, INRIA Rocquencourt, Paris, France.

(15 may 2009) L'auto-organisation dans l'évolution de la parole, Séminaire du Laboratoire Parole et Langage, CNRS, Université de Provence, France.

(6 may 2009) Les défis de la robotique sociale, Atelier de prospective PIRSTEC, ANR/Risc/CNRS, Université Paris VI, Paris, France.

9.3. Teaching

Pierre-Yves Oudeyer gave a 23 hours course on Social and Entertainment Robotics to third year engineering students of ENSTA, Paris.

Pierre-Yves Oudeyer gave a 15 hours course on Social Robotics to second year engineering students of the EMARO International Master of Robotics at the Ecole Centrale de Nantes.

9.4. Communication towards the general public

Interview in Direct Soir (09/01/2009), “Adapter la machine à l'homme, et non l'inverse”.

Article in Inédit, 2009, special issue on man-machine interaction, “Parler aux machines”.

Interviews in Science et Vie, 2009 hors-série “Le siècle des robots”, in two articles (“Les robots nous en disent long sur le vivant” and “Affuter le corps plutôt que la tête”).

Interview in Science et Vie, août 2009, “La science aux portes de l'impossible”.

Interview in Interstices, 2009, “A propos de l'apprentissage des robots”.

Article in Banque des Savoirs, 2009, “ICub à l'image d'un enfant”.

Interview in “Techniques de l'ingénieur”, “Notre objectif est de construire des machines capables de s'auto-évaluer”.

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