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ROBOTIC SOCIETIES: ELEMENTS OF LEARNING BY IMITATION

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ABSTRACT

Imitation enables the individuals to acquire new abilities, and encourages social interaction and cultural transfer. The capability to obtain new abilities by observation represents many important advantages. Although imitation intends to equip robots with social skills, most of the approaches so far only focus on the development of a mechanism to imitate, and other issues that contribute to the whole process of imitation are usually ignored. This paper presents the major elements that are embedded in the process of imitation, and aims to offer a complete framework to address imitation. Experimental results at the first stage with the framework are presented, as well as results using attention process into the perception process.

KEY WORDS

Imitation, Knowledge Acquisition, Learning Behaviour, Perception.

1. INTRODUCTION

The societies have demonstrated an efficient way to ensure the survival of the species. Essentially, the societies have developed knowledge that is used to solve the social problems. Therefore, this transfer and adaptation of knowledge to problems within different contexts have permitted the individuals to develop intelligent behaviour [1]. Thus, the behaviour of each individual in the society is influenced by this social knowledge and the individual also influences the behaviour of other members in the society.

Until now, a number of mechanisms for behaviour learning have already developed in the societies, including conditioning and reinforcement. However, none of these mechanisms is used as much as imitation for knowledge acquisition [2]. Usually imitation is seen as the ability of learning new skills by observation of the conspecifics' actions. Imitation allows the individuals to acquire new abilities, encourages social interaction and cultural transfer. This adaptation enhances the individual's opportunities to be accepted as a part of the society and to survive in it. Then useful behaviours for the survival of the society can be rapidly broaden and passed to the next generation [3].

Since imitation includes stimulus enhancement, social facilitation, emulation and priming [4], it is limited to some animals, which are able to cope with the increasing complexity of interaction between the environment and the individuals, namely primates, cetaceans, and humans [3]. As a result of that, imitation requires significant perceptual, cognitive, and motor capabilities. Many of these have to be developed incrementally during lifetime. Several significant advantages attached to imitation for both individuals and societies are:

- Speed-up the learning process.
- Adaptation.
- No interruption of imitatee's activities.
- Simultaneous learning.
- Implicit communication.
- Compatibility with other learning mechanisms.
- Efficient learning.
- Intelligent behaviour.
- Social interaction.

Roboticists have begun to look imitation for bridging the gap of social robotic systems. However, many questions regard to imitation have to be answered in order to reach the state of learning by imitation that the roboticists expect. Is the robot conscious of itself? Is the robot able to recognize its conspecifics? Does the robot know it is imitating? How does the robot determine what is an appropriate action to imitate? How does the robot adapt actions to new circumstances and environments? When should the robot perform the learnt action? And finally, how does the robot know that it has been successful to perform an action? However, these questions embrace more than what has been already investigated. Each of these questions is an issue to be investigated and shows that imitation is more complex than a simple mechanism for matching actions.

The rest of the paper is organised as follows. Section 2 presents the influence of imitation in robotics, as well as some attempts to create an imitative robotic system. Section 3 gives details of some key issues that describe the process of imitation and the evidence from the research work on cognitive sciences. We also discuss how the elements presented in the framework could represent an improvement in the design of an imitative robotic system. The experiment results are presented in section 4. Finally, section 5 summarises the paper.

2. ROBOTICS AND IMITATION

Robotics researchers have developed many individual robots that are able to solve some specific domain tasks. In practice, many applications require robots working as a team to solve a common problem, including space exploration, hazardous environments, service robotics, cleaning, transportation, emergency handling, house building, and so forth. These require communication and coordination either between the robots or between robots and humans [5]. The robots should be able to cope not only with objects but also with other robots in the same environment.

It is a challenging issue for us to develop a team of robots to perform complex behaviours and present an intelligent interaction with the environment (objects and agents). The traditional approaches to this question (programming and learning strategies) have demonstrated to be very complex, slow and restricted in knowledge [3]. Thus, learning by imitation presents an alternative solution. Roboticists have begun to look at imitation. Since the capability to obtain new abilities by observation represents many important advantages, imitation intends to fill the gap to build social robots. As a result, research in imitation tries to approach the multiple robotic systems, with a social touch. Due to the research into multiple robotic systems has focus their efforts on collective behaviours (flocking, following, homing) of a group of robots, these robots are not able to adapt their behaviour to solve similar problems in new contexts. In addition, there is not a social interaction. Hence, imitation represents an alternative approach to reach the state of social robotic systems, and moreover, imitation is a tool to acquire new behaviours and to accommodate new contexts.

A diversified work on learning by imitation in robotic systems has been done during the last few years. Based on reinforcement learning, Schaal presented a model that was able to achieve imitation of balancing a pole; they used a 7 DOF robot arm as learner and a human demonstrator for this task [6]. Dautenhahn presented agents traverse a hilly landscape, which are attached to the teacher and learn the trajectories [7]. With a specific time the agents are able to recognize suitable teachers.

Hayes and Demiris used an imitation mechanism that maps the observed movements of the teacher to the learner's own movements [8]. Their approach is based on the matched dependent behaviour, which basically consists of associating stimulus in the environment at the time with the appropriate action. They presented a mechanism for attention, which identifies any significant event in the perception. Their strategy was that the learner follows the demonstrator in maze navigation, using simulation and real robots. Their work in [2] had been based on the matching mechanism proposed by Meltzoff and Moore [9], which essentially maps the perceived actions (teacher's actions) with the equivalent actions of the learner. The experiments were also extended with a robot that imitated human head movements.

Gaussier et al [10] presented an architecture that learns by sensory-motor associations with a delayed reward. Their work was inspired from neuroscience, in particular from the hippocampus and cerebellum. Thus, they implemented a system with on-line and unsupervised learning, where both the learning process and the performance of the learned sequence were triggered by an internal state (Motivation or Emotion). The task was to follow a path. The precision of their results is decreased when the intervals' time is increased. Crabbe and Dyer [11] presented an architecture that learns a sequence of steps by observing a teacher. In contrast with other approaches, the learner identifies the goals, and not only imitates the movements. The task presented was building a wall. Despite of that the learner is able to learn a sequence with a single pass of the teacher, the system is unable to invent or modify the observed sequence.

The imitation research group at University of Southern California has presented some research ideas supported by cognitive sciences and neuroscience. Their model of imitation is a result of both, evolutionary motor control structures and a mechanism for simply mimicry [12]. Mirror neurons are the mechanism to achieve the mimicry; these particular neurons map the relationship between the sensory-motor of teacher's actions and the learner's actions. They also provide a classification learning mechanism for new motor primitives. Their model was implemented in several test-beds such as physics-based humanoid simulation, humanoid Avantars (Simulation), Robot dog (Sony AIBO), and wheeled mobile robots (Pioneer). Their experiments included the movements of limbs (arms and legs), Macarena Dance, imitation of arm and finger movements, and imitation of a wooden puppet [13,14,15].

3. FRAMEWORK OF IMITATION

Some approaches to learning by imitation reproduce sequential acts, which are detailed by linear specifications [6,10,12,13,14]. Others reproduce sequential steps which are subroutines being pre-programmed [2,8,11,15]. However, all of these researchers only focus their efforts on the development of a mechanism to imitate, and other issues that contribute in the whole process of imitation are usually ignored. The motivation of this paper is to present the major elements that outline the process of imitation. These elements represent a most complete framework for the investigation of imitation.

A. Mechanism

Meltzoff and Moore [9] presented a mechanism that tends to explain imitation. The imitator* recognises equivalences between body movements that they see. By detecting a mismatch of the current observed state of the

* The imitator is the agent that imitates, and the imitatee is the agent being imitated.

imitatee and the stored representation of the imitator, imitation is triggered in order to reduce this difference. They also proposed that the perception of an action might be registered in such a way that it could be used directly for the execution of a motor plan. Therefore, perception and motor processes share a common language. This mechanism in imitation is called Active Inter-modal Mapping (AIM). The most of the researchers in robotics has focus their attention to the mechanism of imitation. They seem to agree that this mechanism is mainly composed of three fundamental processes: ***Perception***, ***Learning***, and ***Action***.

In addition, it is concluded from experiments in [16] that the imitator matches both the ***form*** and ***temporal*** aspects of the imitatee's demonstration. These also support the idea that imitation is a social act, rather than only a single mechanism that works by reflexes.

B. Self and society

Imitation is a social phenomenon; it is presented only in ***societies***, and encourages the social interaction between the individuals. Therefore, the society has an influence over imitation in a direct way. Apes that are raised within human societies offer a clear example of this influence. The apes are encouraged to develop cognitive skills, which have effect on attention, leading to the enhancement of their abilities for attention [17].

Imitation plays an important part in the development of individual contacts and social relationship in humans, including adults and children. In particular, infants take advantage of this form of learning. Meltzoff and Moore [16] argued that imitation in infants enriches their understanding of the concept of person and actions. It also permits that the infants distinguish between things and persons. All these construct a connection between imitation and the personal ***identity***.

This identity permits the individual to differentiate themselves and the others. Moreover, the identity helps the individual to differ clearly between someone who is analogous in acts and others who are not [18]. In a similar way, the individual can recognize the observed acts and look for the equivalences of their own acts.

C. Experience and goals

The individuals in the societies remember their interactions with the others and the environment. These ***experiences*** outline the way that the individual perceives the world. In contrast, behaviours are regularly related to the mental states. These mental states and behaviours are registered. Thus, all the experiences for which the individual goes through form part of a self-learning. These mental states would lead to ***intentions*** of the individual to achieve a ***goal***.

Many researchers in psychology support the idea that imitation of actions is strongly influenced by the pursuit goal [19,20]. Chaminade et al suggested that human cognition is able to make the distinction between matching an observed action and reproducing the correct use of an object [21].

Imitation assumes that a level of ***novelty*** exhibited by the imitated action is required, which means that the action does not already exist in the action repertoire of the individual [17]. But even a sequence of actions that are already part of the repertoire might be novel. This is because only specific actions lead to the success of a particular task.

D. Language

Imitation employs ***memory*** and ***representation*** of actions, in particular with the deferred imitation. This kind of imitation requires the ability to perform the learnt action after a delay and when the imitatee is not present. Moreover, the deferred imitation requires also not to be attached to a particular context. This would permit to adapt the imitated action to new contexts. The freedom in context plays an important role for language acquisition [18]. Since the words can be used flexibly in new circumstances. Meltzoff and Moore [16] argued that imitation serves as a means of ***communication*** for the infant. Imitation is also used for preverbal children as a way of communication in their social exchanges. This communication via imitation leads to share a repertory of actions and to learn new actions on a social basis [22].

The interactive process between the imitatee and the imitator shows a close relation among imitation and communication. Even though, the communication is often implicit, using cues, grins, grimace, features in the environment, and forth on. This communication supports the ***attention***, and then the imitator is able to discriminate relevant information for the learning process. When the attention is not leaded, the imitator has to select the relevant focus of attention. Using explicit or implicit communication not only leads the attention of the imitator, but it also offers a ***feedback*** to the imitator about the performed action.

Since imitation is a social phenomenon and a means to enhance the social abilities, this framework is situated in the context of social robotic systems (Fig. 1). The proposed framework presents imitation not only as a mechanism to obtain new copied behaviours, but also as a way to recognise the goal from the behaviour demonstrated by other robots. Although, there are many different means that can lead to reach the same goal, the essential effects of the observed behaviour are imitated apart from the particular physical motions. However, imitated behaviours might fail when they are reproduced in some altered environments or even when the environment is the same but the robots have different bodies [23].

Therefore, the aim of this paper is to illustrate a general framework for imitation that would permit to acquire new behaviours through observation. Extracting the goals from the observed actions, which would allow adapting the behaviours to new contexts. Therefore the model would be just a tool that robots use to acquire new knowledge, which could be used to solve a diversity of problems and not a mechanism to solve a specific problem.

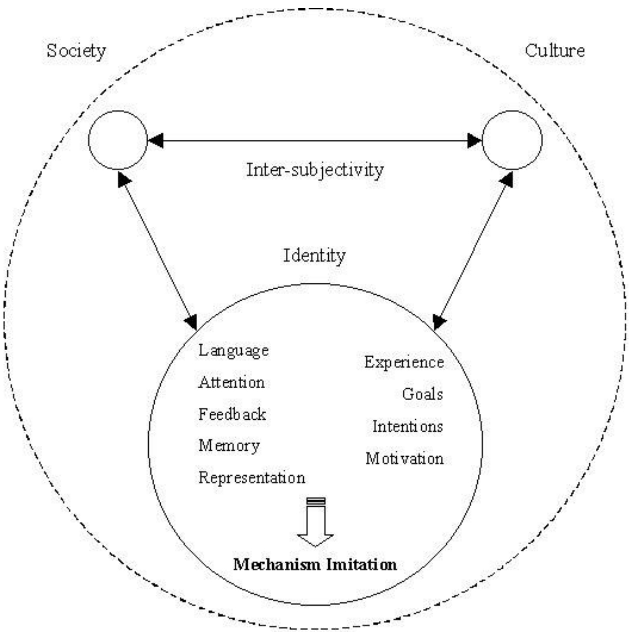

Fig. 1. The framework proposed to approach the behaviour learning by imitation.

The approach presented in this paper intends to achieve three objectives:

- First, it proposes a comprehensive framework of learning by imitation. The proposed model takes account of the details presented by cognitive sciences. In addition, the model is a general-purpose architecture for imitation. It is not designed to a particular problem.
- Second, it identifies the goal from an observed action. When the goal is known, diverse means to achieve it can be applied. Extracting the goal from an observed action would allow the robot to decide when to apply a particular behaviour.
- Finally, it aims at adapting the learnt behaviours to the new context, which is more important than learning behaviours itself. Moreover, the individuals should be able to adapt the learnt behaviours when the context has changed.

Imitation might equip robots with the abilities to be efficient in applications requiring human interaction. And eventually, robots with social skills are able to help humans in personal tasks. Thus, the robots might work in different environments, learning new behaviours and adapting their knowledge to solve new problems.

4. EXPERIMENTAL RESULTS

Imitation is characterized in societies for the elements described above. We presented these elements as a more comprehensive framework to achieve imitation. In this section, experiments are carried out, which concern only to the matching mechanism and perception at this stage.

The experiments have been conducted in our Brooker laboratory. Two Pioneer 2 mobile robots have been used as the imitator and the imitatee respectively. Each mobile robot is endowed with the basic components for sensing and navigation in a real-world environment. In addition they are equipped with a vision system and a colour tracking system.

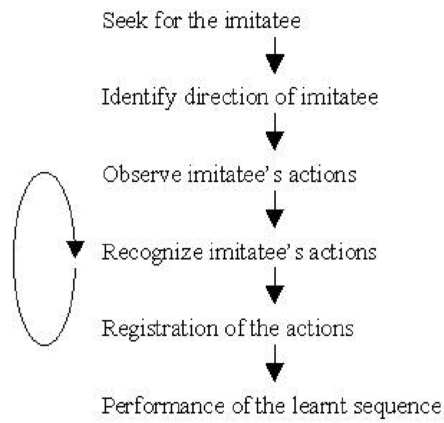

Fig. 2. The algorithm employed by the imitator to imitate the actions of the imitatee.

The experiment was conducted in two phases (Fig. 2). First, in the teaching phase, the imitator observes the movements of the imitatee in order to learn from it. Meanwhile, it also associates the perceived actions with its own states, which already are part of its action's repertoire. The second is the performing phase; the imitator will reproduce the learnt sequence of movements. The system consists of three processes as follows.

The perception process allows identifying the imitatee's movements. The colour tracking system provides information about the position and size of the coloured objects, for this particular case the imitatee.

The action process offers the manipulation of the drive motors. A repertoire of motor primitives composes the motor process. Thus, primitives might vary their output according to the parameters received. This representation and memory allow the imitator to achieve the deferred imitation. Moreover the use of parameters in the primitives makes the motor process more flexible to execute the imitated behaviour in a new context, instead to make a copy of the behaviour. For example, the imitator could vary the velocity of a particular action or all the actions in the sequence to achieve a particular goal.

The last one is ***the learning process***. This is responsible to match the observed movements with the motor primitives, but also to learn the sequence of these motor primitives taking into consideration parameters such as time and speed for each primitive involved in the sequence.

In Fig. 3, the imitatee robot is at the starting position (top left), moves forward and stops (Top right), then moves backwards and stops (Bottom left), and finally moves forward and reaches the goal position (Bottom right).

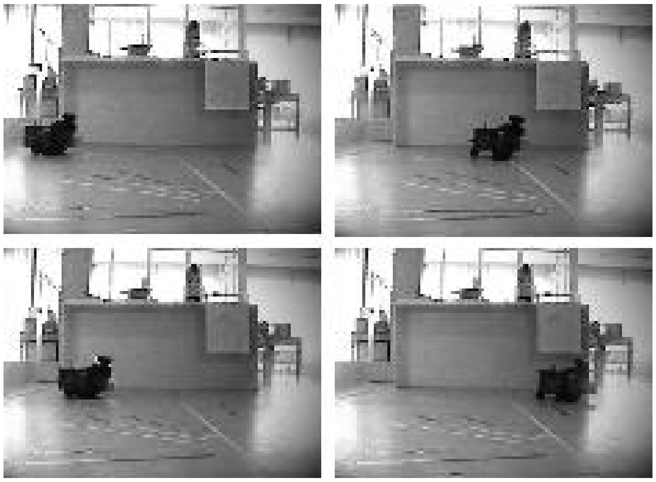

Fig. 3. A sequence of 5 actions shown by the imitatee (forward, stop, backward, stop, and forward).

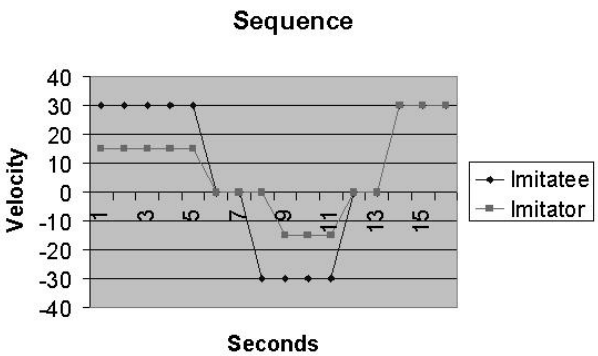

Fig. 4. A sequence of 5 actions done by both the imitatee and the imitator(forward, stop, backward, stop, and forward).

In Fig. 4, we can see that the imitator has changed some of the velocities in some of actions as adaptation of the behaviours in a new environment.

The perception is one of the most complex problems in robotics systems. Since the robot has to find the correspondence between the sensorial data and the current task. Communication between imitatee and imitator helps to achieve this selection. Humans use social cues to ease the process of perception and thus determine salient features of the environment.

The imitatee could direct the attention of the imitator to relevant features of the task [24]. Hence, the imitatee could use language, gaze direction or pointing the desire feature; in this way, the imitator is able to extract the relevant data from the incoming sensory signals.

Therefore, our experiments have extended integrating an attention process into the perception process. Using those processes permit the imitator to identify salient features in the environment. Thus, the imitator is able to change its gaze direction to focus salient features.

A variety of characteristics might catch the attention of the robot, such as colour, motion, texture, orientation, light levels, etc. We have chosen as characteristics for the attention process. Colour, to make simpler the detection of desired features. And motion, because actions require physical movements.

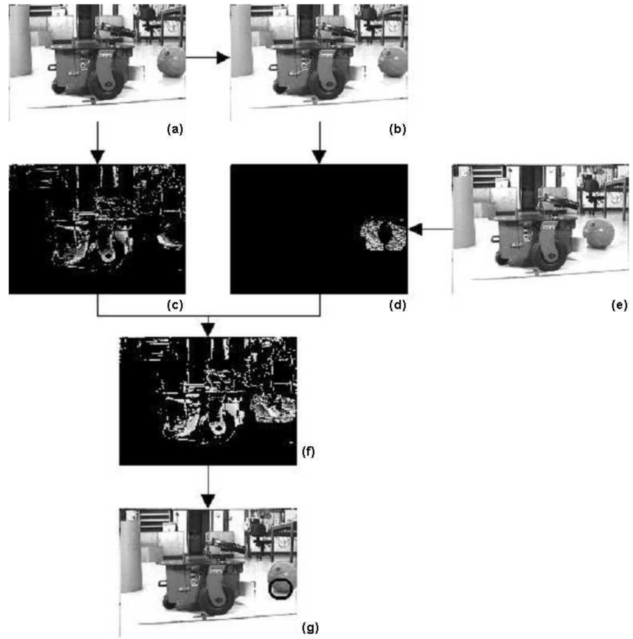

Fig. 5. The perception-attention process. Using Colour map and Motion map to obtain the Salient map.

In Fig. 5, the imitator obtains a colour image (a) from the camera, which is used to obtain the areas that contain the desired colour; these areas are marked into the colour map (c). Meanwhile, the colour image is converted into a greyscale image (b), which is used to obtain the areas that have changed since the previous frame (e); these areas are marked into a motion map (d). Both maps are merged into a salient map (f), the output of these map serves as input for the new gaze direction (g).

5. CONCLUSIONS AND FUTURE WORK

Imitation is a powerful form of learning used by many animals. This learning method has permitted the societies to transfer and adapt knowledge between the members in order to solve their problems, in particular ensuring the survival of the society. Also imitation encourages the social interaction and the cultural transfer. Researchers in both psychology and neuroscience have done some extensive investigation on imitation, which has inspired the roboticists. However, research in robotics is mainly focused on the development of the imitation mechanism, and other issues that contribute in the whole process of imitation are usually ignored.

The paper presents some key elements that delineate the process of imitation. These elements offer a complete framework to the development of imitation. In other words, the framework presents a comprehensive model of learning by imitation, namely Mechanism, Self and society, Experience and goals, and Language.

This general framework for imitation would permit a robot to acquire new behaviours through observation. Extracting the goals from the observed actions would allow the robots to adapt their behaviours to new contexts. Therefore the proposed model should be a useful tool for the robots to acquire new knowledge and solve particular problems; and it is not a mechanism to solve any specific problem. The contributions of the framework include:

- A comprehensive framework of learning by imitation
- Identifying the goal from an observed action
- Adapting the learnt behaviours to new contexts

We have described our experiments in a multiple robotic system setting that consists of two robots, i.e. an imitatee and an imitator. Our experiments show the feasibility of the proposed framework at its first stage. Results using an attention process to drive the perception are also presented. Our next aim is to include the other elements in the proposed framework in order to increase the complexity of the tasks to be imitated.

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