

Robot Imitation from Human Body Movements

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Abstract

Imitation represents a useful and promising alternative to programming robots. The approach presented here is based on two functional elements used by humans to understand and perform actions. These elements are: the body schema and the body percept. The first one is a representation of the body containing information of the body's capabilities. The body percept is a snapshot of the body and its relation with the environment at a given instant. These elements are believed to interact between each other generating among other abilities, the ability to imitate. This paper presents our approach to robot imitation and experimental results, where a robot is able to imitate the movements of a human demonstrator via its visual observations.

1 Introduction

Today, many robotics applications are being investigated, including space exploration, hazardous environments, service robotics, cleaning, transportation, emergency handling, house building, elderly assistance, and so forth (Liu and Wu, 2001; Fong et al., 2002). These novel applications involve interaction between humans and robots where the robots must coordinate their efforts with their human owners. Therefore, robots must be able to recognize the observable actions of the other teammates in order to understand the goals of the actions (Breazeal et al., submitted for publication). In addition, some robots must also learn new observable actions in order to be able to exchange roles with their teammates. Nevertheless, the introduction of robots in places where humans live or work requires safety, functionality, and effective human-robot interaction (Zollo et al., 2003).

It is here where imitation arises as a very promising approach. Imitation, the ability to recognize, learn and copy the actions of others, rises as *a very promising alternative solution to the programming of robots*. It remains a challenge for roboticists to develop the abilities that a robot needs to perform a task while interacting intelligently with the environment (Bakker and Kuniyoshi, 1996; Acosta-Calderon and Hu, 2003b). Traditional approaches to this issue, such as programming and learning strategies, have been demonstrated to be complex, slow and restricted in knowledge.

Imitation could equip robots with abilities to per-

form *efficient human-robot interaction*, eventually helping humans in personal tasks (Acosta-Calderon and Hu, 2003b; Dautenhahn and Nehaniv, 2002; Becker et al., 1999). It also seems that imitation could be a tool to acquire new behaviors and to adapt these within new contexts (Acosta-Calderon and Hu, 2003a).

Imitation has several advantages that can be transmitted from humans to robots. In humans, this ability permits one to treat the other as a conspecific (Meltzoff and Brooks, 2001) by *perceiving similarities between oneself and other*. This sort of perspective shift may help us to predict actions; enabling us to infer the goal enacted by one another's behaviors (Breazeal et al., submitted for publication).

Our approach to robot imitation is based on how humans acquired the necessary information to understand and execute action (Acosta-Calderon and Hu, 2004a). In humans, the information required to perform an action is obtained from two sources: the body schema, which contains the relations of the body parts and its physical constraints; and the body percept, which refers to a particular body position perceived in an instant (Acosta-Calderon and Hu, 2004b). The body schema and the body percept give us the insight into recognizing actions and thereby performing these actions, therefore, *The understanding of other people's actions would lead to imitation (Oztop and Arbib, 2002)*. We use these fundamental parts and describe their relation throughout four developmental stages used to describe the imitative abilities in humans. This paper describes our approach to ad-

dressing imitation of body movements. Results of experiments with a robotic platform implementing mentioned approach are also described. Related works on imitation using robotics arms focus on reproducing the exact gesture, which means to minimize the discrepancy for each joint (Ilg et al., 2003; Zollo et al., 2003; Schaal et al., 2003). The work described here uses a different approach: to focus only on the target and to allow the imitator to obtain the rest of the body configuration. This approach is valid when the imitator and the demonstrator do not share the same body structure.

The rest of the paper is organized as follows. Section II presents the background theory that has inspired our work on imitation. Section III describes briefly the body configuration. In Section IV we present our mechanism for imitation of body movements and implementation issues for the robotic platform. Experiment results are presented in Section V. Finally, Section VI concludes the paper.

2 Background

Humans can perform actions that are feasible with their bodies. To achieve those actions humans use the information derived from two sources (Reed, 2002):

- *The body schema* is the long-term representation between the spatial relations among body parts and the knowledge about the actions that they can and cannot perform.
- *The body percept* refers to a particular body position perceived in an instant. It is built by instantly merging information from sensory input and proprioception; with the body schema. It is the awareness of a body's position at any given moment.

The body schema presents two significant functions, which use the knowledge of the feasible actions that every part of the body can perform:

- *Direct action.* When an action is performed from a current position, a new one is produced.
- *Inverse action.* When an action that satisfies a goal position is selected.

The interaction of both functions allows one to *simulate another person's actions* (Goldman, 2001). When a goal state is identified, then the inverse action generates the motor commands that would achieve

the goal. Those motor commands are sent to the direct action which will predict the next state. This predicted state is compared with the target goal to take further decisions.

These two functions share the idea that has been used in motor control but they are known as controllers and predictors. Demiris and Johnson (2003) used functions with the same principle but called them inverse and forward models.

When we observe someone performing a particular action, one can easily determine how one would accomplish the same task using one's own body. This means that it is possible to *recognize the action* that someone else is performing. The body schema provides the basis to *understand similar bodies and perform the same actions* (Meltzoff and Moore, 1994). This idea is essential in imitation. In order to imitate, it is first necessary to identify the observed actions, and then to be able to perform those actions. Thus, in order to achieve a perceived action a mental simulation is performed constraining/restraining the movements to those that are physically possible.

There are different approaches to describe the way that humans develop the ability to imitate. One attempt to explain the development of imitation is given by Rao and Meltzoff (2003), who had introduced a four-stage progression of the imitative abilities. Details of those four stages are presented below:

- *Body babbling.* This is the process of learning how specific muscle movements achieve various elementary body configurations. Thus, such movements are learned through an early experimental process, e.g. random trial-and-error learning. Thus, Body babbling is related to the task of building up the body schema (the physics of the system and its constraints).
- *Imitation of body movements.* This demonstrates that a specific body part can be identified i.e. organ identification (Meltzoff and Moore, 1992). Here, the body schema interacts with the body percept to achieve the same movements, once these are identified.
- *Imitation of actions on objects.* This stage starts underlying mental stages about others' behaviour and oneself. This also represents flexibility to adapt actions to new contexts.
- *Imitation based on inferring intentions of actions.* This requires the ability to read beyond the perceived behaviour to infer the underlying goals and intentions.

These four developmental stages serve as a guideline for our progress in research. This paper reports mainly our experiences accomplishing imitation of body movements with a robotic system. We also describe briefly our work on body babbling.

3 Body configuration

Body babbling endows us with the elementary configuration to control our body movements by generating a map. This map contains the relation of all the body parts and their physical limitations. In other words, this map is the body schema.

As humans grow and their bodies change, the body schema is constantly updated by means of input from the body percept. The body percept, in turn, gathers its information from sensory and proprioception information. If there is an inconsistency between the body schema and the body percept, then the body schema is updated.

In robotics, since the bodies of robots are changeless in size and weight, body babbling is simplified by endowing the robot with a control mechanism. Such a mechanism must permit the robot to know its physical abilities and limitations. Therefore, for the experiments with the robotic platform we use the kinematic analysis as the mechanism of position control. The *forward kinematic analysis* calculates the position and orientation of the *gripper* of the robot. In similar way, to determine the values of the robot's joints to produce a desired position and orientation, we use the *Resolve Motion Rate Control (RMRC)*. Further details of these methods and implementation issues can be found in (Acosta-Calderon and Hu, 2004a,b)

4 Imitation of Body Movements

4.1 Identification of a body part

The first step towards imitation is the recognition of the action to imitate. Hence, the imitator must be able to differ among the demonstrator's body parts to identify those those to imitate. The approach described here uses key ideas of the mirror neurons.

These particular neurons have been found in macaque monkeys. These neurons fire when the monkey observes movements executed by another monkey or human demonstrator, as well as when the monkey executes similar goal-oriented movements (Oztop and Arbib, 2002). Neuropsychological experiments in humans described in (Buccino et al.,

2001; Charminade et al., 2002) have revealed brain regions that present similar activity to the one presented by mirror neurons, for both perception and execution of action.

One interesting feature is that, mirror neurons only fire when they perceive similar body parts to the monkey's (mechanical devices do not activate them). Hence, the detection of the similar body parts tends to release the mirror neurons' activity.

Psychologists propose a innate observation-execution pathway in humans (Meltzoff and Moore, 1992; Charminade et al., 2002), here, mirror neurons give a good insight into understanding this idea. Therefore, we can use the same idea of mirror neurons to identify a body part. However, an interesting question arises: do we need to implement a mirror neuron model to every single part of the body? If so, the model would be extremely complicated due to the number of possible combinations of body parts.

The solution could be in an insight of how human beings focus attention on body parts. When humans observe a body movement they do not focus their attention on every single body part. Instead, humans focus their attention on the "end-effector", discarding the position of the other body parts (Mataric, 2002; Mataric and Pomplun, 1998). The body schema finds the necessary body configuration for the rest of our body's parts thereby satisfying the target position for the end-effector.

The implementation of the identification model is done within the body schema module. Here, the end-effector of the demonstrator is marked in distinct color, which can be easily extracted from the image. For our purposes is sufficient to use this simple approach.

Therefore, it is important to remark *the level of imitation* Billard et al. (2004); Dautenhahn and Nehaniv (2002); Nehaniv and Dautenhahn (2002) used in this work. The level of imitation utilized here is *the reproduction of the path followed by the target*, where the imitator will only focus to follow the path described by the end-effector of the demonstrator. The level of *reproduction of the exact gesture* was not chosen due to our approach allows the body schema to find the body configuration satisfying the target position. The discrepancy among the bodies of the imitator and the demonstrator supports the validation of the level of imitation selected. Nevertheless, this discrepancy of bodies arises a problem: the correspondence problem.

4.2 The Correspondence Problem

A successful imitation requires that the imitator be able to recognize structural congruence between oneself and the demonstrator (Meltzoff and Brooks, 2001). When both the demonstrator and the imitator have a common body representation, the body schema of the imitator is then, by itself, capable enough to understand the demonstrator's body. Nevertheless, in a situation where the demonstrator's body differs from the imitator's body schema, there must be a way that the imitator can overcome this so called *correspondence problem* (Nehaniv and Dautenhahn, 2001, 2002). For our implementation, this correspondence problem is worked out by providing the representation of the body of the demonstrator and a way to relate this representation (Acosta-Calderon and Hu, 2004a).

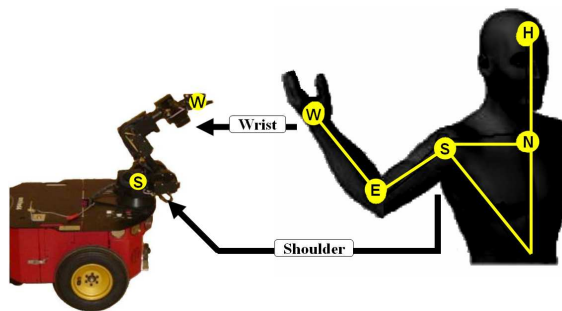


Figure 1: The correspondence between the bodies of the robot (left) and the demonstrator (right). Two joints, the shoulder and the wrist, have correspondence in both bodies.

Figure 1 presents the correspondence between the body of the demonstrator and that of the imitator. Here, a transformation is used to relate both representations. This transformation is based on the knowledge that in the set of joints of the demonstrator there are three points that represent an arm (shoulder, elbow, and wrist). The remaining two points (the head and the neck) are used just as a reference. The reference points are used to keep a relation among the distances in the demonstrator model. This information about the representation of the demonstrator is extracted by means of color segmentation.

The transformation relates the demonstrator's body to the robot's body. The demonstrator's shoulder is used as the origin of the workspace of the robot. Hence, the shoulder of the demonstrator is treated as the reference point for the calculation of the remaining two points of the demonstrator's arm. Note that only the position of the demonstrator's end-effector

(wrist) is then converted and fitted into the workspace of the robot.

Each new position of the end-effector identified in the workspace of the robot triggers the body schema to fulfill it. Since the robot only cares about the position of the end-effector, it uses the body schema (the control method) to obtain the rest of the body configuration (Acosta-Calderon and Hu, 2004a).

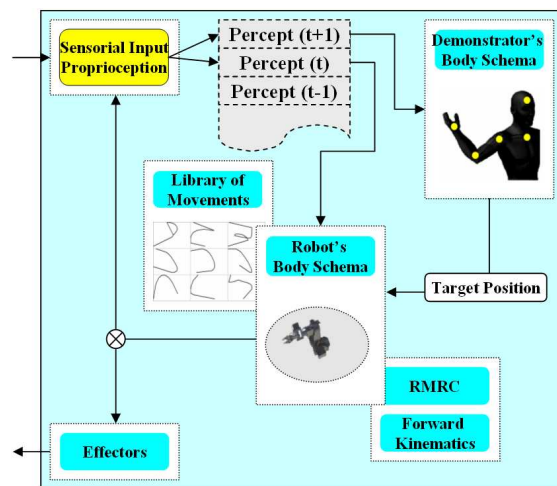


Figure 2: The architecture used to imitate the body movements. The information about the demonstrator is extracted and then converted to the robot's workspace. This information represents the new position to be imitated.

The mechanism implemented for the imitation of body movements is depicted in Fig. 2. Hence, to satisfy a new position of the end-effector the body schema employs the *inverse action* function (Resolve Motion Rate Control - RMRC). This function obtains the new values for the body parts to satisfy the desired position. The body configuration obtained leads to a controllable motion preventing the joints from moving too fast whilst the kinetic energy is minimized; just like humans do when we imitate *the path described by the target* and not *the exact gesture*. Further details of the RMRC implemented can be seen at Acosta-Calderon and Hu (2004a).

Although, the body configuration obtained for the robot, might not be similar to the one presented by the demonstrator. Instead of copying the extract posture, the level of imitation that we are addressing is to reproduce the same goal position. This is mainly because the robot and the demonstrator do not share the same body structure. This can avoid the situation where one body configuration can not be achieved by physical constraints. Here, the body schema plays

a crucial role minimizing the motion between positions, while considering the physical constraints, and selecting the more efficient body configuration.

Once a body configuration has been found this can either be sent to the actuators and executed, or inhibit the output to the actuators and send it to the *direct action* function (Forward Kinematics). The direct action will simulate the action of sending those values to the actuators and return the achieved position for that particular set of values. The new reached position is used to generate the current body percept, as the new position, in other words, a mental rehearsal of the observed action.

4.3 Movements

The movements imitated are represented as paths consisting of a set of points. Each point represents the demonstrator's end-effector both the position (defined in Cartesian coordinates by x, y , and z) and the orientation (defined by the *roll, pitch*, and *yaw* angles) (Acosta-Calderon and Hu, 2004a,b).

Each new position in the movement of the demonstrator is smoothed by using *cubic spline curves*. These kinds of curves have the feature that they can be interrupted at any point and fit smoothly to another different path. More points can be added to the curve without increasing the complexity of the calculation. Using spline curves reduces the noise in the data from the color segmentation.

The identification of a movement is a complex process. In the process of identification it is necessary to find, if there is, a matching movement from the previously learnt movements in the library.

The matching process consists of comparing a movement with those already stored in the library, and selects the one with the minimal error defined by (1)

$$\varphi_k = \arg_i \min \left(\vec{f} - \vec{f}_i \right)^2 \quad (1)$$

where φ_k is the minimal error for the movement in the library with the index k . \vec{f}_i is the function that represents the featuring vector of the movement with index i , as shown in (2). The minimal error obtained from the elements in the library does not guarantee the new element corresponds to a similar class of movements. Hence, the minimal error φ_k is compared with a threshold. When φ_k is less than the threshold, it is assumed that the observed movement is close enough to the one represented by the best match k . Thus, the movement k in the library is updated using interpolation with the observed movement. On the other hand, when φ_k is greater than the

threshold, the observed movement would be treated as a new movement and finally added to the library. This process can be seen from Fig. 3

$$\vec{f}_i = (f_1, f_2, \dots, f_N) \quad (2)$$

The extraction of the features for the movement i is performed by using a *grid-based extraction* as described by Shen and Hu (2004). This method divides an image into a fixed number of cells N defined by the number of *columns* and *rows*. The next step is to visit each cell j in the grid and the number of Relevant Features RF counted. Finally, this value is normalized by the total number of Relevant Features of the movement i via (3).

$$f_j = \frac{RF_j}{\sum RF_j} \quad (3)$$

After visiting all the cells, all the feature values f_j are collected into the featuring vector \vec{f}_i . The values contained in the featuring vector are relative values, which are robust to variations in the slope of the movement. A variation in the slope of a sub-area of the movement does not represent a significant variation in the featuring vector.

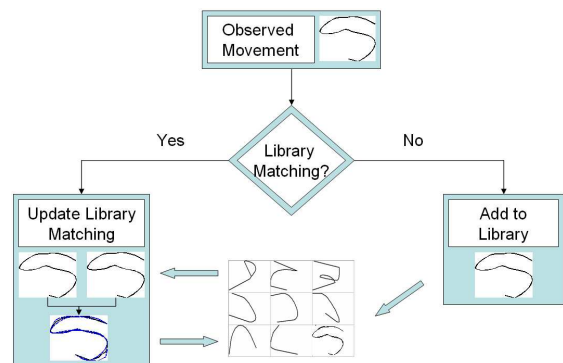


Figure 3: Interpolation of the library movement (a) with a new movement (b) the result is movement (c).

Figure 4 presents two movements divided into sub-areas by the grid. In order to compare both movements they must have the same scale, the same number of columns and rows, and of course, the same number of pixels in each sub-area of the grid.

5 Experimental results

To investigate the abilities of the approach presented, we described our experience with experiments of imitation of actions on objects. In our set-up we used

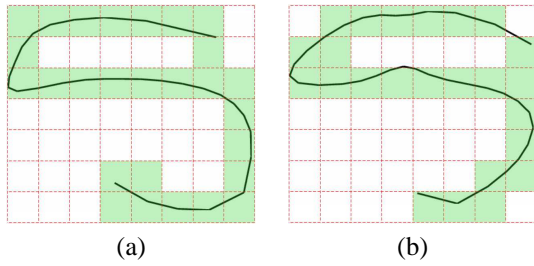


Figure 4: Two movements are divided into cells and to be compared.

the robot United4, as the imitator, which faced a human demonstrator. The robot observed the movements performed by the demonstrator in order to imitate them later. The experiments were conducted in two phases for all the cases:

- *Learning phase*, in which the robot was observing the demonstrator's movements, while identifying and recording them to be executed later.
- *Execution phase*, here the robot performs the movements learnt in the previous phase.

The robotic platform used is a mobile robot Pioneer 2-DX with a Pioneer Arm and a camera, namely United4. The robot is a small, differential-drive mobile robot intended for indoors. The robot is endowed with the basic components for sensing and navigation in a real-world environment. It is also equipped with a color tracking system. United4 has a Pioneer Arm, which is a robotic arm with five *degrees-of-freedom*, the end-effector is a gripper with fingers allowing for the grasping and manipulation of objects.

The experiments have been conducted in our Brooker laboratory. The relevant objects in the environment (demonstrator's joints) were marked with different colors to simplify the feature extraction. The less cluttered background permits the robot to focus only on the significant information. We also consider only planar motions in order to validate our approach.

Our first set of experiments of movements of body parts involved movements describing different paths. In Figure 5, we present one path used in the experiments.

In Fig. 5, (a), (c), and (e) show the demonstrator performing a path from up to down with his right hand. While (b), (d), and (f) present the robot imitating such movement. In addition, We can observe that the robot presented *the mirror effect*. Hence, if the demonstrator, located in front of the robot, moves its

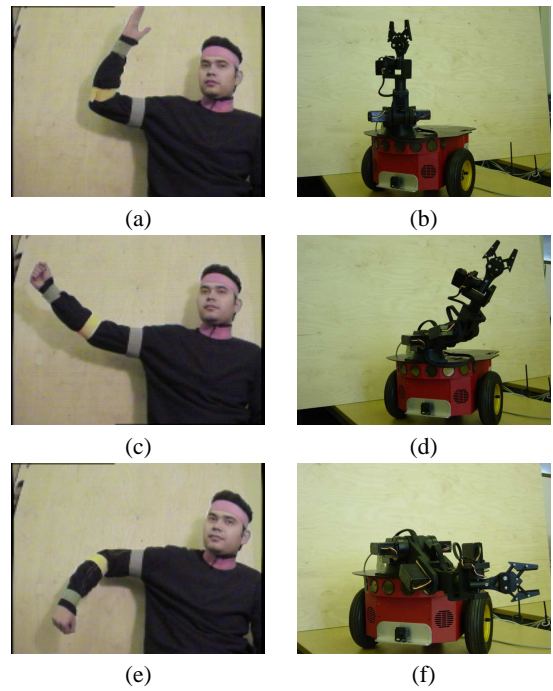


Figure 5: Movements performed by the demonstrator and imitated by the robot.

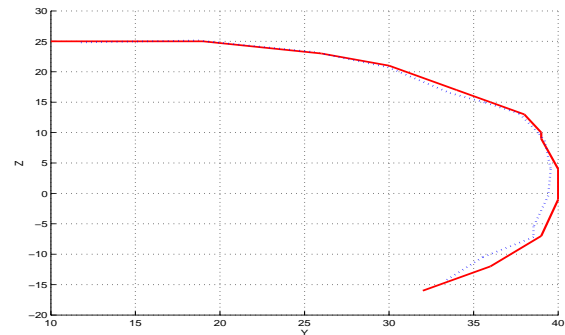


Figure 6: The movement of the demonstrator (solid line) and the performance of the robot (dotted line), extracted from the movements in Fig. 5.

left arm, then the imitator would move its arm toward the right, acting as a mirror.

In Fig. 6, the solid line is the path extracted from the movements performed by the demonstrator in Fig. 5. The dotted line represents the robot's performance. The path was extracted and adjusted in order to be performed by the robot since the size and shape of the workspace for the model and the robot were not the same.

The second set of experiments on imitation of body movements involved movements writing different letters, e.g. e, s. The robot observed the demon-

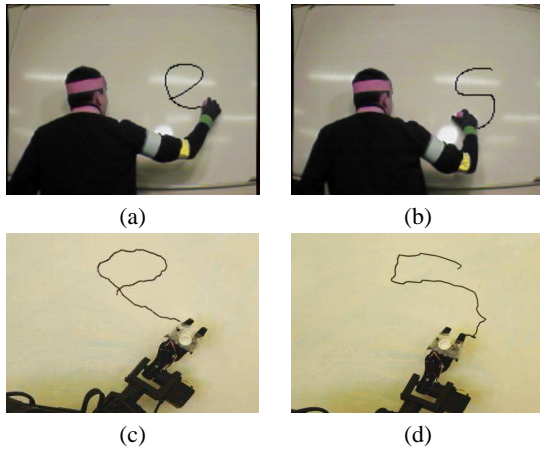


Figure 7: During the learning phase, shown in (a) and (b) the demonstrator is writing the letters “e” and “s”. During the execution phase, shown in (c) and (d) the robot is writing those letters.

strator performing the handwriting while, by means of the colored markers that the demonstrator wears, the body representation of the demonstrator was extracted. This representation was related with the robot’s representation by the body schema. Therefore, the robot could understand the new position of the demonstrator’s end-effector within its workspace. The configuration needed to reach this desired position was eventually calculated by means of the kinematics methods. Finally, the path described by the end-effector was recorded and ready to be executed.

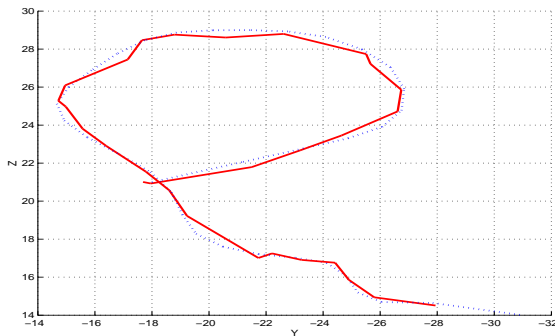


Figure 8: Letter “e.” The solid line is the performance of the robot (from Figure 7.c), and the dotted line is the path that the robot generated after observing the demonstrator’s performance (from Figure 7.a).

Figure 7 presents the letters “e” and “s.” The learning phase is presented in (a) and (b), where the demonstrator has written these letters. When the demonstrator was describing the path of these let-

ters, the robot was observing and relating those movements to its own. In the execution phase, (c) and (d), the robot is performing the paths described by the letters.

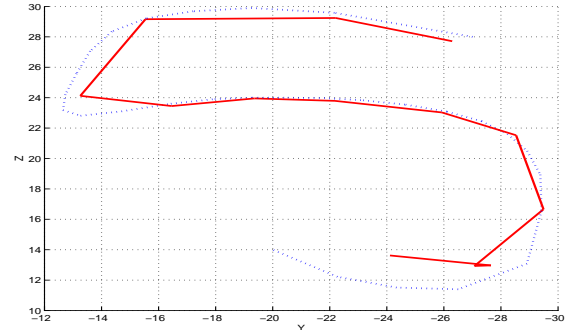


Figure 9: Letter “s.” The Performance of the robot in the solid line (from fig. 7.d), and the dotted line is the path that the robot generated by observing the demonstrator performance (from fig. 7.b).

Each path is extracted and adjusted in order to be performed by the robot since the size and shape of the workspace for the model and the robot are not the same. To minimize the noise in the path, we smooth the path by using *cubic spline curves*.

6 Conclusions and future work

Roboticians have begun to focus their attention on imitation. Since the capability to obtain new abilities by observation presents considerable advantages in contrast with traditional learning approaches. Finally, imitation might equip robots with the abilities for an efficient human-robot interaction.

The presented approach is based on *the body schema* and *the body percept*, which are used by humans to understand how other people perform actions. Since the knowledge of feasible actions and physical constraints is implicit in the body schema, it is possible to do a mental rehearsal of other people’s actions and gather the results of those actions at particular body percepts for the body schema. It is believed that these two key-parts play a crucial role in achieving imitation.

We used an approach of four developmental stages of imitation in humans, to prove the key-role of these two components. The scope of this paper describes our progress mainly on imitation of body movements. In this stage, we used the idea to focus on the end-effector as humans do and to allow the body schema to obtain the rest of the configuration.

We have also described our experiments with a robot as the imitator, imitating the movements of a human demonstrator. Our experiments show the feasibility of the proposed approach at this stage of imitation. Our future work involves extending the experiments to the next stage, imitation of action on objects.

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