An Approach of Manipulator Control for Service-robot FISR-1 Based on Motion Imitating

L.B. Yu, Q.X. Cao, X.W. Xu
Research Institute of Robotics
Shanghai Jiao Tong University
Shanghai, P.R. of China
Email:{lbyu, qxcao }@sjtu.edu.cn

Abstract –**According to other experts' researches, it is necessary for the motion of service-robot manipulator should either be anticipated or be familiar to people. In order to realize this prospect, we propose that service-robot should imitate the motion of manipulator taught by people. In this paper we use the prototype of dual arm mobile service-robot FISR-1 (Family Intelligent Service Robot-1) to study the approach of manipulator control for motion imitating. The motion FISR-1 should imitate is using its right arm to touch a block on a table.**

In order to make FISR-1 touch a new positioned block with an imitative motion, the approaches suggested by other researches before are not appropriate. So a new approach is proposed based on these approaches. The robot extracts joints value for sample motion with Hidden Markov Model (HMM) from original demonstrative motion first, and then the robot creates a new motion based on the sample motion according to keep the trajectory of each joint similar. Simulations are presented to illustrate the validity of this approach.

Index Terms –**Service-robot, manipulator control, motion imitating**

I. INTRODUCTION

With the advance in computer science and robotics, robots are now more applicable to our daily life, and service-robots will be more and more popular. Most approaches of manipulator control for service-robots have not considered the effect of motion to human psychology [1]-[3]. Although these approaches can make the manipulator of service-robots move faster or with shorter trajectory etc., the advantages in kinematics may become the disadvantages for service-robots being popular with people. The manipulator motions of robots which are not familiar to human as well as which can't be expected will make person anxious to stay with them.[4]-[6] So it is necessary to develop a new approach of manipulator control for service-robots with which the motion of manipulator can be either familiar to people or be expected.

In recent years, some approaches of motion imitating have occurred for manipulator control.[7]-[9] Although the robot can imitate the demonstrative motions with these methods and the control may be robust, however, the robot will have no ability to create new similar motions automatically, i.e. the motion imitating is limited. And it is not appropriate for these approaches to be used in the manipulator control of FISR-1 who needs to create new similar motions in a dynamic environment.

By the stimulus, we propose a new approach of manipulator control based on these approaches which is used by Aude Billard with HMM in paper [8] and paper [9]. A manipulator motion of touching a block on table is used to explain the approach. First some demonstrative motions are required, and then the robot analyzes the kinematics data such as joint angle etc for a sample motion with HMM. [8]-[10] If a new position of the block is detected, robot will calculate the terminal angle of joints when the manipulator touches the block. According to the similarity between new trajectory and the trajectory in sample motion for each joint, a new trajectory can be calculated. An imitating motion is acquired based on the new trajectories of joints.

Finally a simulation was carried out, and the results are presented in this paper for verifying the validity of the approach.

II. MOTION LEARNING

FISR-1 has been developing in our laboratory which will be used as a family assistant. Its 3D virtual model is depicted in Fig.1. It has 6 degrees of freedom (DOF) per arm which includes 5 revolute joints and one gripper, and there is one revolute DOF in waist, driven by two differential wheels in base. $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$ are the notation for rotary angle of revolute joints on right arm, and the kinematic transformation

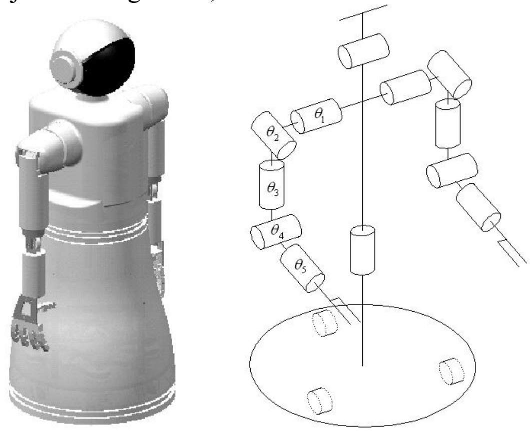


Fig.1 A 3D and kinematics model for virtual FISR-1

equations are presented as follows. ${}^iT_j$ means the kinematics transformation from joint j to joint i, while ${}^5T_{end}$ means it transforms from the end-effect to joint 5.

978-1-4244-1706-3/08/$25.00 ©2008 IEEE.

The initial values for parameters in equations are depicted in Table.1.

$$ {}^{0}T_{1} = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ 0 & 0 & -1 & d_{1y} \\ \sin\theta_1 & \cos\theta_1 & 0 & d_{1z} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

$$ {}^{1}T_{2} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ -\cos\theta_2 & \sin\theta_2 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

$$ {}^{2}T_{3} = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & 0 \\ 0 & 0 & -1 & d_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

$$ {}^{3}T_{4} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ -\cos\theta_4 & \sin\theta_4 & 0 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

$$ {}^{4}T_{5} = \begin{bmatrix} \cos\theta_5 & -\sin\theta_5 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ -\sin\theta_5 & -\cos\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5) $$

$$ {}^{5}T_{end} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6) $$

TABLE 1 THE INITIAL VALUE FOR PARAMETERS IN EQUATIONS ABOVE

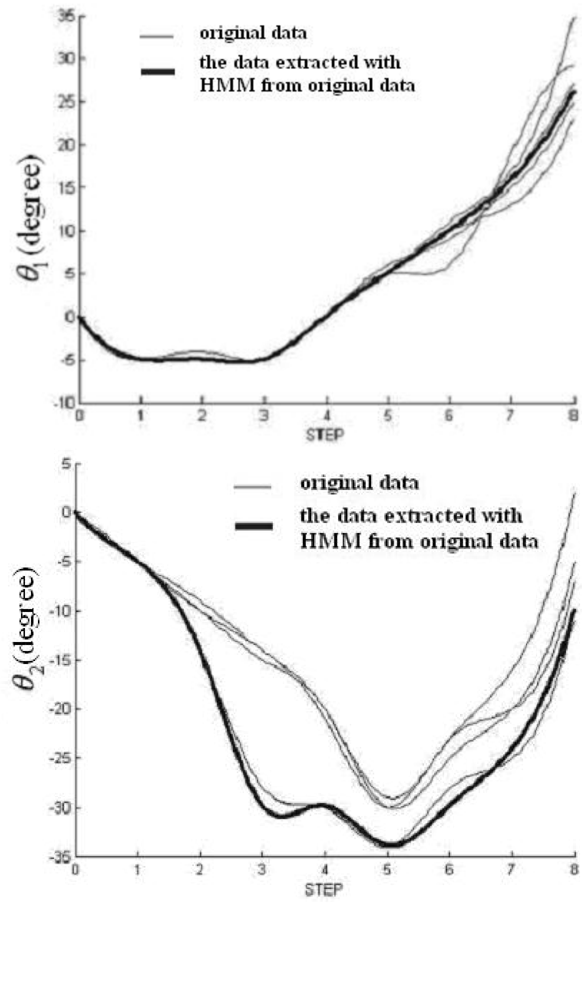
Joint angle	Value (degree)	Displacement value	Value (mm)
θ_1	0	d_{1y}	-150
θ_2	0	d_{1z}	863
θ_3	0	d_2	150
θ_4	90	d_3	-228
θ_5	0	d_4	40
		d_5	158
		d_6	173

Suppose FISR-1 stands statically, and a block is placed on the table in front within its manipulator reachable space. Experiment of touching the block is carried out in virtual environment, and we demonstrate for 5 times using the right arm, while keeping the left arm in the original position. The block positions value relative to the robot in 5 times are depicted in Table.2.

TABLE 2 THE VALUE OF POSITION FOR BLOCK IN EACH TIME

Coordinates \ Time	1	2	3	4	5
X (mm)	400	431	420	406	433
Y (mm)	-164	-120	-196	-219	-234
Z (mm)	550	550	550	550	550

It is apparently that these positions (x, y, z) adjoin to each other. Because of the deviations exist these five motions shouldn't be same, but there may be some constant contents in the different motions for their adjoining position. The constant contents in motions always are the most probable occurrence. In order to extract the constant contents from original motions, we apply HMM to extract the largest probable angle for each joint, and these data will be used to constitute a sample motion. Both the original data and the calculated data for each joint are showed in Fig.2, and the axes of STEP represent 8 key steps in motion. The thin curve is original data of angle, and the thick curve is the data extracted with HMM. We can apply such data extracted with HMM to make a sample motion.



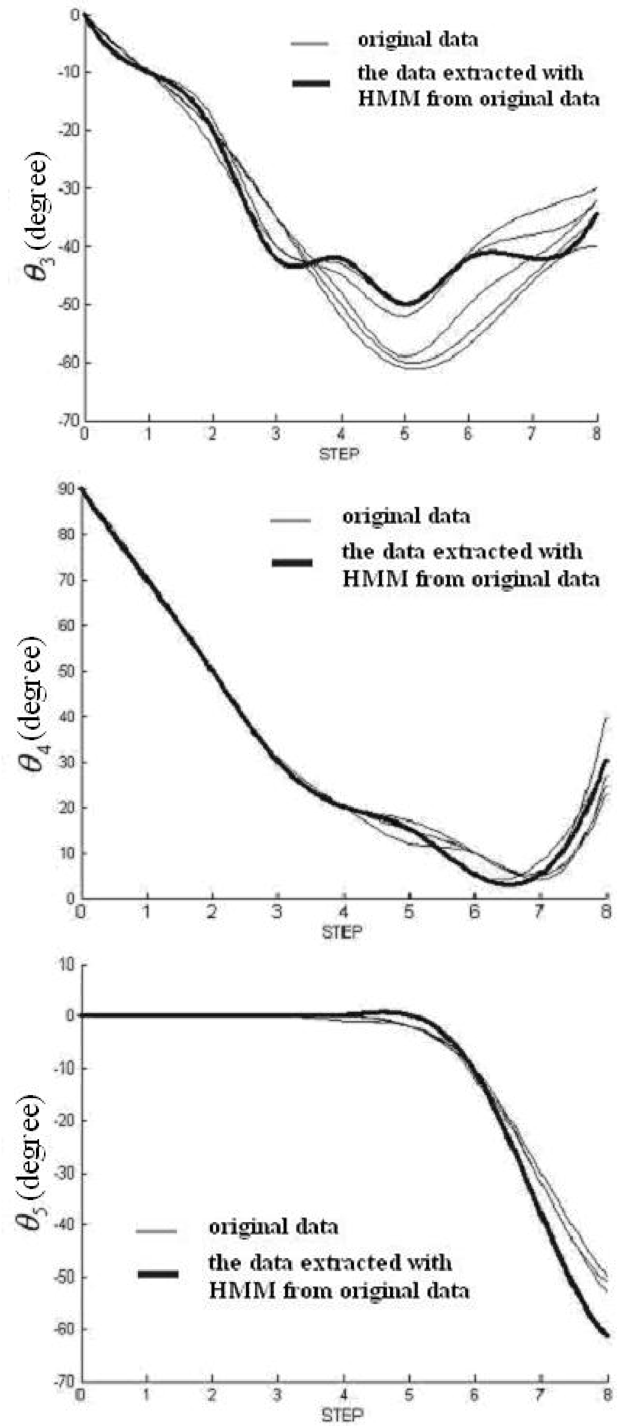


Fig.2 The value of original and extracted angle with HMM

III. Motion Imitating

We calculate the deviation between original joints angle and the sample motion joints angle in all of eight steps. The sum of these deviations is composed of the factor notated as σ_j and the formula is:

$$\sigma_j = \frac{1}{5}\cdot \sum_{i=1}^{5}\sum_{k=0}^{8}\sqrt{\left(\theta^{i}_{jk}-\theta_{jk}^{H}\right)^2} \qquad (7)$$

Where θ^{i}_{jk} is the original angle for joint j in step k, θ_{jk}^{H} is the data extracted with HMM. The results are presented in the Table.3 as follows.

TABLE 3 The Value of σ_j for Each Joint

σ_j	σ_1	σ_2	σ_3	σ_4	σ_5
Value (mm)	28.2280	302.2507	259.9221	60.9183	94.2248

Then we define a factor notated as ω_j, and an equation

$$\omega_j = \sigma_j \Big/ \sum_{j=5}\sigma_j \qquad (8)$$

Where the value of ω_j implies how much extent for the robot can change the trajectory of joint j based on the trajectory in sample motion. If the value of ω_j is small means the robot should keep this joint rotating as the same trajectory as that in sample motion, while ω_j is large representing that the robot can change this joint's trajectory much in the new motion. The results are presented in Table.4.

TABLE 4 The Value of ω_j in Motion

ω_j	ω_1	ω_2	ω_3	ω_4	ω_5
Value (%)	3.79	40.54	34.86	8.17	12.64

So we can define an equation

$$\theta_{jk}^{\circ} = \theta_{jk}^{H} + l_{jk}\cdot\Delta\theta_{jk} \qquad (9)$$

Where $l_{jk} = 1$ or -1, $j = 1,2...5$, $k = 0,1...8$. Suppose the block is detected in a new position $(350,-90,550)$, According to the definition of ω_j, we simply impose $\Delta\theta_{1k} = \Delta\theta_{4k} = 0$ for their ω_j are less than others. Now the left $\Delta\theta_{jk}$ will calculated with inverse kinematics. The approximate solutions of θ_{j8}° for the manipulator touching the block are showed in Table.5.

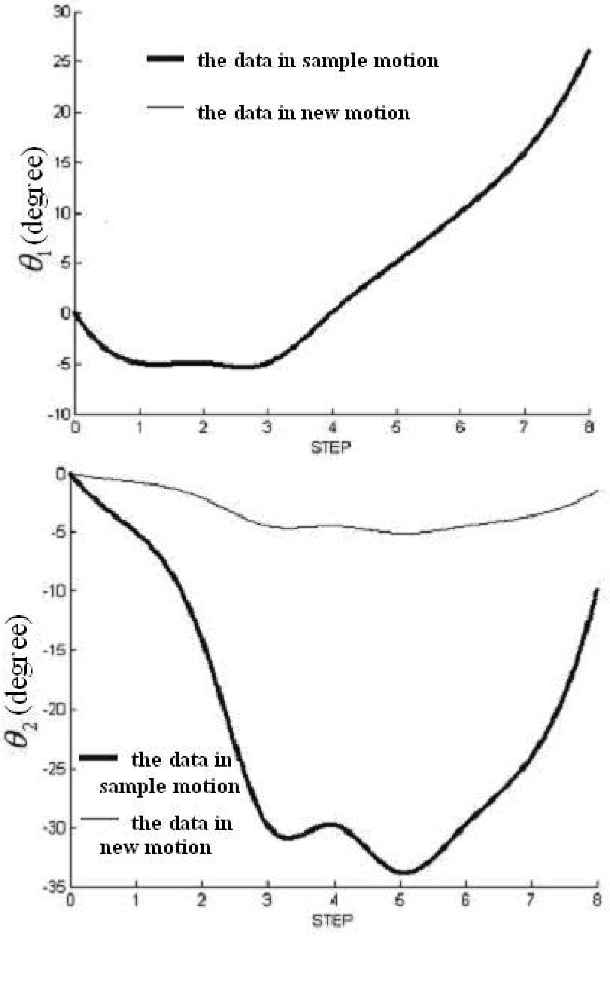
TABLE 5 THE VALUE OF JOINTS ANGLE FOR END-EFFECT TOUCHING BLOCK

Joint angle	θ_{18}^{H}	θ_{18}^{H}	θ_{18}^{H}	θ_{18}^{H}	θ_{18}^{H}
Value (degree)	25.9807	-9.994	-34.557	30.0151	-61.473
Joint angle	θ_{18}°	θ_{28}°	θ_{38}°	θ_{48}°	θ_{58}°
Value (degree)	25.9807	-1.4940	-51.057	30.0151	-66.473

Let define the following function:

$$\theta_j^{\circ} = \theta_j^{H} \cdot \left(\left(\theta_{j8}^{\circ} - \theta_{j0}^{\circ}\right) \Big/ \left(\theta_{j8}^{H} - \theta_{j0}^{H}\right)\right) \quad (10)$$

Where $j = 2,3,4$ and $\theta_{j0}^{\circ} = \theta_{j0}^{H}$, $\theta_j^{\circ}, \theta_j^{H}$ are the desired angle for new motion and the angle in sample motion separately. The results are showed in Fig.3, and the thin curve is θ_j°, while thick curve is θ_j^{H}.



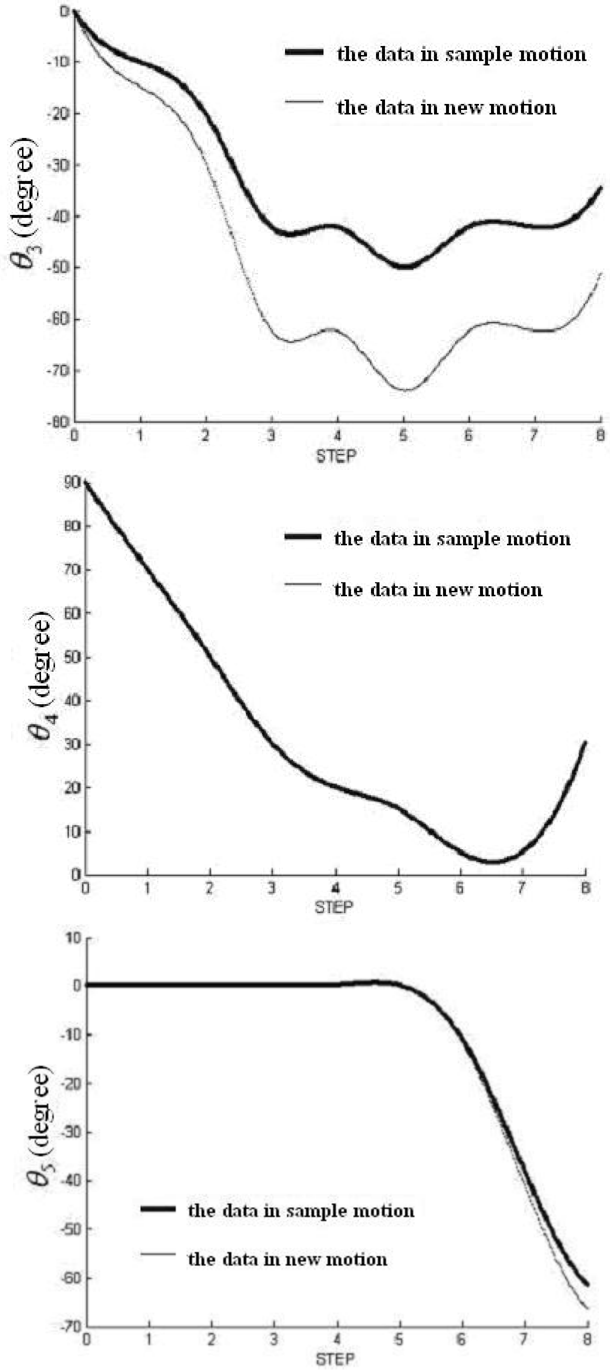


Fig.3 The value of angle for sample motion and new motion

Finally, we apply these new joints data to control manipulator working, and the simulations are presented in Fig.4. The left figure is the sample motion, and the right figure is the new imitative motion. We can see that it is similar for their motion of bending right elbow toward torso, and then raising hand, eventually pushing the end-effect upon the block on the table.

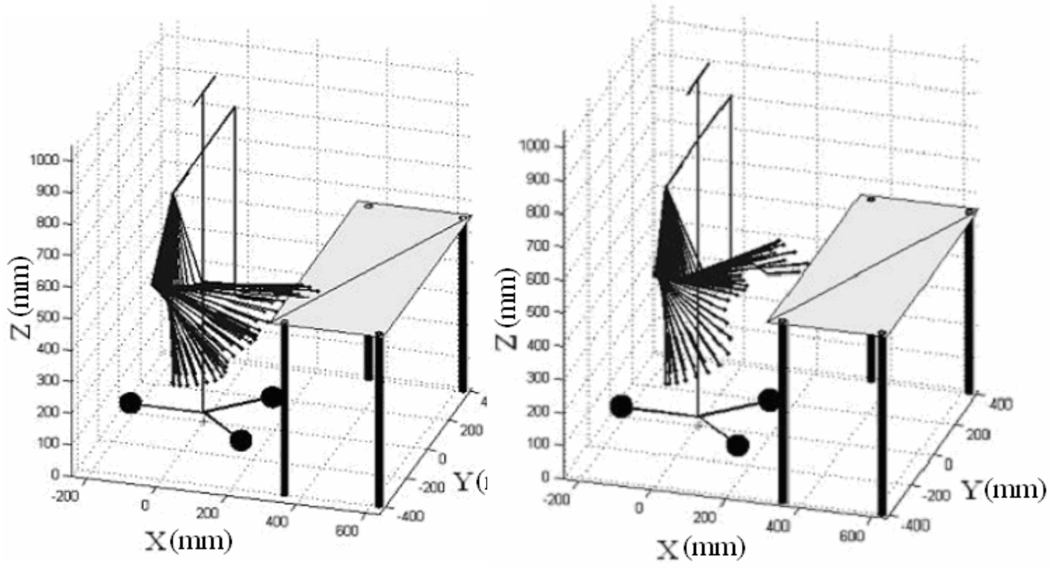


Fig.4 Simulation of sample motion and new motion

IV. CONCLUSIONS

In this paper we propose an approach of manipulator control for service-robot FISR-1 touching a block on table which will make the service-robot create a new motion similar to the motion taught by people. The proposed approach includes two steps: (1) extracting sample motions from original motions demonstrated by people, (2) changing the trajectory of each joint and make it be similar to the trajectory in the sample motion according to the new position of the block. Because of the similarity of the joints rotation, this approach realizes the similarity between the sample motion and a new motion. So the manipulator implements the task of touching the block in new position, and furthermore the new motion is imitating the sample motion. The simulations demonstrate the validity of the approach and the optimization of motion imitating will be further studied in future.

V. ACKNOWLEDGMENTS

This work is supported by the Chinese 863 Program (Grant No. 2006AA04Z261)

REFERENCES

[1] John Q. Gan , Eimei Oyama†, Eric M. Rosales , *"A complete analytical solution to the inverse kinematics of the Pioneer 2 robotic arm"*, Robotica (2005) volume 23, pp. 123–129.

[2] Mirosław Galicki, *"Adaptive path-constrained control of a robotic manipulator in a task space"* , Robotica (2007) volume 25, pp. 103–112.

[3] Shigang Yue*,a Dominik Henrich*, W. L. Xu† ,*"Point-to-Point trajectory planning of flexible redundant robot manipulators using genetic"*, Robotica (2002) volume 20, pp. 269–280.

[4] Dana Kuli´c and Elizabeth Croft , *"Physiological and subjective responses to articulated robot motion"* , Robotica (2007) volume 25, pp. 13–27.

[5] Y.Matsumoto, J.Heinzmann, A.Zelinsky, *"The Essential Components of Human-Friendly Robot Systems"*, Proceedings of the International Conference on Field and Service Robotics, pp.43-51, Pittsburgh, USA,August 29-31, 1999.

[6] Dana KuliC Elizabeth Croft ,*"Safe Planning for Human-Robot Interaction"*, ProCMdlngL of the 2004 IEEE lnmrnational Conhnnce on Robtics 6 Automation New Orleans. LA &rll2004.

[7] Auke Jan Ijspeert & Jun Nakanishi & Stefan Schaal, "*Movement Imitation with Nonlinear Dynamical Systems in Humanoid Robots",* Proceedings of the IEEE International Conference on Robotics and Automation, 2002

[8] Sylvain Calinon, Florent Guenter and Aude Billard, *"Goal-Directed Imitation in a Humanoid Robot"*, Proceedings of the 2005 IEEE International Conference on Robotics and Automation Barcelona, Spain, April 2005.

[9] Sylvain Calinon & Aude Billard,*"Stochastic gesture production and recognition model for a humanoid robot"*, Proceedings of the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems, Septemeber 28-October 2, 2004, Sendai, Japan.

[10] L. Rabiner,*"A tutorial on hidden markov models and selected applications in speech recognition"*, Proceedings of the IEEE, vol.77:2, pp. 257–285, February 1989.