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MNSM-Inspired Method for the Motion Control of Dual-Arm Robot

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***Abstract*— This work presents a MNSM (Mirror Neuron System Mechanism) inspired method to control the motion of a dual-arm robot. The new symmetrical action can be classified as instinct-following arbitrary trajectory and goal-based motion; they are planned by the dual-arm robot planner, and implemented by the dual-arm robot within a master/slave protocol. The master arm uses a motion planner to generate corresponding signal for the motor neuron. Then the motor neuron controls the motor to move the joint of the robot. The activities of motor neuron can also fire the MNSSL (Mirror Neuron System of Symmetry Limb) and it will generate the code about the movement and pass it to the receiver of the MNS (Mirror Neuron System) in the slave arm. The MNS of the slave arm will decode the information to generate the corresponding signal of the motor neuron to drive the motor to move the joints. The effective symmetrical motions are also linked with different vocabularies, and all these are stored in the memory as knowledge.**

High level mirror activities fired by high level neuron command, speech stimulus, etc will use the knowledge in the memory to control the dual-arm robot to realize different symmetrical motions.

This study provides not only a new method for the dual-arm robot to realize some given motion task, but also firstly a way by robot motion demonstration to understand the mirror movement mechanism between human's symmetrical limbs.

I. Introduction

(a) Single arm (b) Dual arm

Figure 1. Arm posture and its indication for "love"

(a) Single arm (b) Dual arm

Figure 2. Arm posture and its function for "hold"

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Multi-fingered hands with symmetrical gestures can represent broader meanings, and these meanings are difficult to be expressed with one hand. For example, from Fig.1 (a), we can not understand its intention; while Fig.1 (b) can clearly show it means "love".

Besides, two arms with symmetrical posture can also do more things, such as with the posture shown in Fig.2 (b) people can hold a ball, while with the posture shown in Fig.2 (a) people can not do it.

Dual-arm robot manipulation is an interesting topic [1]. Typically, dual-arm robot motion planning problem is NPC (Nondeterministic Polynomial time Complete), its complexity grows exponentially as the number of DOF (Degree of Freedom) increases [2]. It also needs prevent from colliding between the two robots. K. Yoshida et al based on the redundancy resolution technique to study on torque optimization through dual-arm coordination [3]. P. Ćurković et al studied on a cooperative coevolutionary approach on path planning for two robotic arms sharing common workspace [4]. Y. Guo et al developed an adaptive neural network controller for the coordinated motion planning of dual-arm space robot system [5]. M. Gharbi et al presented a method for planning dual-arm coordinated manipulation paths based on an extension of the PRM (Probabilistic Roadmap Method) algorithm to closed-chain mechanisms [6]. The symmetrical motion of dual-arm is a typical mirror movement where one arm mirrors the movement of the other one. Mirror movement occurs in the infant, and will disappear after myelination of corpus callosum. As for the normal individuals, mirror movement happens during marked physical activity or with severe fatigue. With efforts, there is increase in the mirror movements. Mirroring is generally more obvious on one side compared with the other [7]. Mirror movement is a diesis found in adult for a particular gene mutation [8].

Neuroscientists find out that there are mirror neurons in our bodies which are responsible for different kinds of mirror activities. A mirror neuron is a neuron which fires both when performing an action and when observing the same action performed by another (possibly conspecific) creature (or symmetry limb for infant or adult with mirror movement diseases) [9]. Every time an individual observes an action performed by another individual, or hears the sounds related to the action, see the words related to the action, the neurons that represent that action are activated in the premotor cortex. Inspired by above viewpoint, a MNSM (Mirror Neuron System Mechanism)-based method is proposed to control the symmetrical motion of a dual-arm robot. The motion of one arm will evoke the mirror neuron system of the other arm. The mirror neuron system can adopt different mirror mechanism to generate an action to cooperate with the master arm. Finally

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the effective symmetrical motion is also associated with a vocabulary. Motor action, speech, and high level neuron command can activate this mirror neuron system to perform the symmetrical motion.

The remainder of this paper is organized as follows: In section II, the related works are specified. Section III presents MNSM-based control system for the typical symmetrical motion generation for a dual-arm robot. A MNSM-based control system for knowledge execution with speech stimulus is addressed in section IV. In section V, some experiments related to an object manipulation scenario are carried out with motion information to validate the proposed control method. Finally, the conclusions and future works are discussed in section VI.

II. Related Works

The existence of a mirror-like visuomotor activation in the human brain is firstly evidenced by a TMS (Transcranial Magnetic Stimulation) experiment where Broca's area is taken as the core center of the human mirror-neurons system [10].

The schema design and implementation of the grasp-related mirror neuron system is proposed in [11].The evolutionary basis for language parity is provided by the mirror system for grasping, rooting speech in communication based on manual gesture, which provides a neural basis for the claim that hand movements grounded the evolution of language[12,13]. The reach-grasp action related mirror neuron system studies were also published in [14-17].

The mirror neuron system's principles offer inspiration for developing the control strategies of robotic systems. For example, the Mirror-Bot robot was able to associate and recognize verbal commands, visual input and perform related motor actions [18].

C. Weber reviewed the related mirror neuron system based control for robot grasp action. A self-organized neuron network was also proposed with un-supervised learning to realize grasp action [19].

L. Craighero et al proposed a mirror-like representation can be developed autonomously on the basis of the interaction between an individual and the environment [20, 21].

Based on the survey of related topics, little paper is reported on how to use the mirror neuron system mechanism between symmetry limbs to control the symmetrical motion of a dual-arm robot.

III. MNSM-Based Control Method for the Generation and Store of the Symmetrical Motion of the Dual-arm Robot

A. Related theory

C. Weber et al proposed that mirror neuron system is a self-organized neuron network; it can generate a representation for action of another creature or symmetry limb. The action can be associated with a vocabulary to generate a new knowledge. Then with this knowledge, the mirror neurons might be the role of action recognition and understanding [19]. The mirror movement between two arms is generally more obvious on one side compared with the other side [7]. So we can use master/slave protocol to define the movement mechanism between the two arms. Among the joints of master arm, the activated motor neurons can self-organize to generate a signal to activate the mirror neuron system in the slave arm.

B. MNSM-based control system architecture

In this work, the MNSM-based control method is proposed to plan the symmetrical motion of the dual-arm robot. The system architecture is shown in Fig.3.

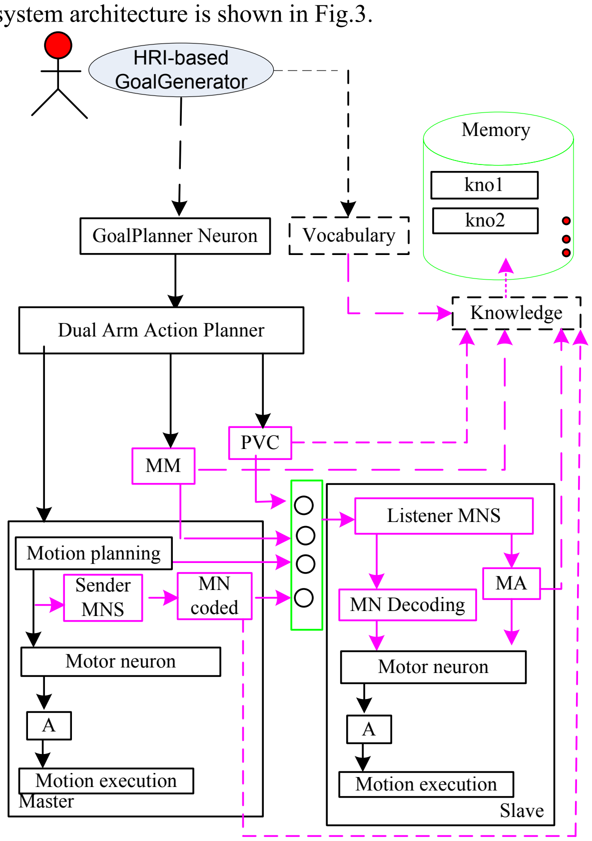


Figure 3. MNSM-based control system architecture for dual-arm robot symmetrical motion control

The goal is generated from HRI (Human Robot Interface)-based *GoalGenerator* with detailed description, such as goal ID, goal name, goal type, arm start posture, arm end posture, etc. The symmetrical movement can be instinct following arbitrary trajectory or goal-based motion. Besides, through human robot interaction, the action can be associated with some object manipulation task. The human instructs the robot to locate the object, and use suitable posture to manipulate the object.

The goal is also sent to dual-arm robot action planner. The planner will (1) decompose the goal, (2) choose one arm as master and arrange the arm posture for it, (3) select the connection method *MM* for the mirror neuron connection between the master arm and slave arm, and (4) define *PVC* for the joint mirror methods for position, velocity between the master and slave robot. Based on the motion knowledge from the planner, the master generates joint angle control information, and sends it to its motor neurons. The motor neurons generate the control signal to drive the mater robot to move. The *Sender* of the mirror neuron system can perceive this neuron information, and code it as motion knowledge *MNcode* for broadcasting. *MNcode*, *PVC* and *MM* are taken as the input to fire linkage network to generate the signal for the listening MNS in the slave arm. The input information is decoded by the MNS to generate the control signal for the motor neurons and amplitude modulation parameters *MA* to cooperate with the amplitude parameters of the joints *A*. The motor neurons can use this information to drive the motor to move joints of the slave robot.

A vocabulary is chosen to describe for the effective motion and together with the motor knowledge code and connection method to generate a high level action knowledge which will be saved in robot memory.

C. Motion knowledge

The effective symmetrical motion can also be classified as final-posture related motion and whole-process related motion.

- Final-posture related motion

  The result of some motion only related with the final posture of the dual-arm configuration. The master can plan this action in joint space; the two arms need not synchronize during the movement. And the robot also need not care about the start posture. Typical, these kinds of actions are suitable for symmetrical {hold, open, close, reach, release, grasp, etc}.

- Whole-process related motion

  The effective motions are not only related with the start posture and end posture of the robot, but also need plan the velocity of the related joint, so as to make the motions achieve the desired goals. These kinds of motions are suitable for symmetrical {pass, lift, push, drag, turn, twist, etc}.

The knowledge information is expressed in the following formation:

PartName	ActionName	ArmType	ActionType	MNCode	MM

Here, *PartName* is a string with *arm* as the default value; *ActionName* is a string with different vocabulary to show the effective of the action; *ArmType* is a bit where 1 means dual arm motion, and 0 means single arm motion; *ActionType* is enumeration type, here 0 means final-posture related motion, and 1 means whole-process related motion.

MNCode is the mirror neuron information to plan this motion. *MNCode* for one joint is with the following formation.

ID	C	SA	FA	P	AV	V	MA

Here we use a normalized method to present the joint angle and velocity, where

$$SA_{\{i\}}=(StartAngle_{\{i\}}-Min\_pos_{\{i\}})/(Max\_pos_{\{i\}}-Min\_pos_{\{i\}}) \quad (1)$$

$$FA_{\{i\}}=(FinalAngle_{\{i\}}-Min\_pos_{\{i\}})/(Max\_pos_{\{i\}}-Min\_pos_{\{i\}}) \quad (2)$$

$$AV_{\{i\}} = (Planned\_Angle\_vel_{\{i\}}-Min\_vel_{\{i\}})/(Max\_vel_{\{i\}}-Min\_vel_{\{i\}}) \quad (3)$$

Where $ID_{\{i\}}$ is the neuron *ID* number; $SA_{\{i\}}$ is the start angle information of joint *i*; $Start\_Angle_{\{i\}}$ is the real start angle of joint *i*; $FA_{\{i\}}$ is the final angle information of joint *i*; $Final\_Angle_{\{i\}}$ is the real final angle of joint *i*; $Min\_pos_{\{i\}}$ is the minimum angle of joint *i*; $Max\_pos_{\{i\}}$ is the maximum angle of joint *i*; $AV_{\{i\}}$ is the angle velocity information of joint *i*; $Planned\_Angle\_vel_{\{i\}}$ is the real angle velocity of joint *i*; $Min\_vel_{\{i\}}$ is the minimum angle velocity of joint *i*; $Max\_vel_{\{i\}}$ is the maximum angle velocity of joint *i*; i= 0…n-1, *n* is the number of joint in one robot arm. $C_{\{i\}}$ is mirror method of joint *i*, here is 1 or -1.$P_{\{i\}}$ is mirror method of joint *i* to perform this action, here is 1 or -1.$V_{\{i\}}$ is mirror method of joint *i* velocity to perform this action, here is 1 or -1.$MA_{\{i\}}$ is modulate coefficient of joint *i*, together with $A_{\{i\}}$ which is the fatigue movement coefficient to realize the symmetrical motion.*MM* has two bits, the first bit is used for mounted method where 1 means same direction mounted arm and -1 means dual-arm type; and the second bit is used for mirror method , where 1 means the same direction mirror, -1 means the inverse direction mirror, and 0 means no mirror.

The master use the information drive the arm move from start posture to final posture with given velocity, and broad cost the real joint information with the same normalized method for joint angle and velocity.

$$RAB_{\{i\}}=(Real\_Angle_{\{i\}}-Min\_pos_{\{i\}})/(Max\_pos_{\{i\}}-Min\_pos_{\{i\}}) \quad (4)$$

$$RBV_{\{i\}} = (Real\_Angle\_vel_{\{i\}}-Min\_vel_{\{i\}}) / (Max\_vel_{\{i\}}-Min\_vel_{\{i\}}) \quad (5)$$

Where $RAB_{\{i\}}$ is the real angle information of joint *i*; $Real\_Angle_{\{i\}}$ is the real angle of joint *i*; $RBV_{\{i\}}$ is the real velocity information of joint *i*; $Real\_Angle\_vel_{\{i\}}$ is the real angle velocity of joint *i*.

The information is perceived by the mirror neuron and send to the receiver of the mirror neuron in the slave robot.

The slave arm uses the decoding neuron network to get the desired signal information for the motor neuron to control the motor. The formulas are shown as following:

$$RAS_{\{i\}}=((Recieved\_Angle\_bit_{\{i\}})*(Max\_pos_{\{i\}}-Min\_pos_{\{i\}})+Min\_pos_{\{i\}})* A_{\{i\}} * MA_{\{i\}} \quad (6)$$

$$RVS_{\{i\}}=((Recieved\_Velocity\_bit_{\{i\}})*(Max\_vel_{\{i\}}-Min\_vel_{\{i\}})+Min\_vel_{\{i\}})*VM_{\{i\}} \quad (7)$$

Where $Recieved\_Angle\_bit_{\{i\}}$ is the recieved angle information of joint *i*; $RAS_{\{i\}}$ is the real angle of joint *i* for the slave robot; $RVS_{\{i\}}$ is the received velocity information of joint i; $Real\_Velocity\_slave_{\{i\}}$ is the real angle velocity of joint i for the slave robot.

IV. MNSM-BASED CONTROL SYSTEM ARCHITECTURE FOR KNOWLEDGE EXECUTION WITH SPEECH STIMULUS

A. *Related theory*

The mirror neuron system can be fired by vision system, and motor activities, etc. While a typical input for human is the language, since our brains have Broca's area, a crucial speech area, which provides a neurobiological "missing link" for the long-argued hypothesis that primitive forms of communication based on manual gesture preceded speech in the evolution of language [12]. In this study, Speech is selected directly to stimulus the MNS to represent the symmetrical motion knowledge.

B. *MNSM-based control system architecture for knowledge execution with speech stimulus*

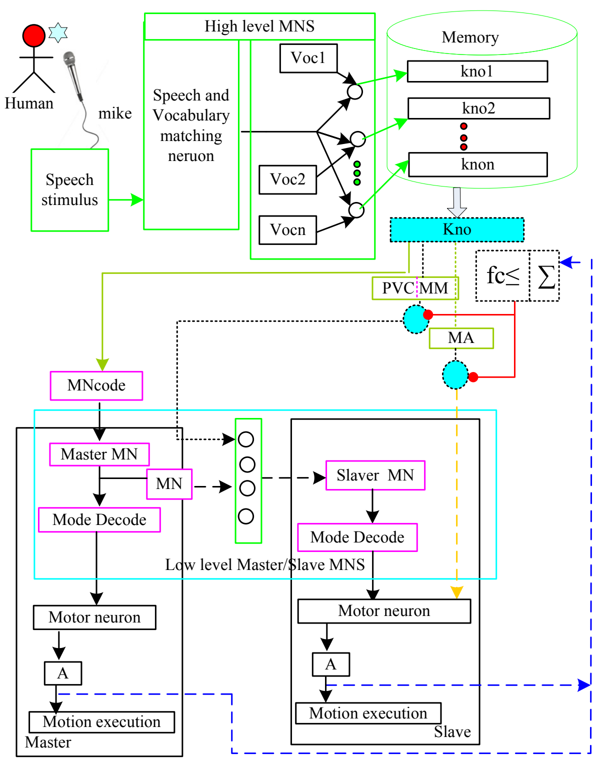


Figure 4. MNSM-based control system architecture for knowledge execution with speech stimulus

In this system, speech is selected as one of the stimulus to activate the high level MNS's activity. Through speech recognition the action selection neuron is activated to index the knowledge from the memory. Normally, the motion knowledge is sent to the MNS of the master arm. The MNS will broadcast this information, and decode the information to generate the motor neuron signal to control the joints. The receiver part of the MNS will receive this information. Together with the PVC (Position, Velocity, Control) information and MA (Modulate Amplitude) information to generate the input for motor neuron to drive the slave robot to realize the symmetrical movement.

Based on the research from neuron scientist that "normal adults can also show mirror activity, which is the electrical concomitant of mirror movements and has been observed in normal individuals during marked physical activity or with severe fatigue" [7]. Here we use a fatigue function to describe this mirror movement.

$$Fn = \begin{cases} 0, & if \sum Motion\_Number \le fc \\ 1, & if \sum Motion\_Number > fc \end{cases}$$

Where, Fn is the output of fatigue neuron, and fc is the fatigue factor. $\sum Motion\_Number$ means the total number of the motion action in a given execution time.

The activity of the motor neuron can update the value for fatigue function, when it reaches its limitation, it fires and its output will prohibit the normal movement, and result in a mirror movement. When it happens, the slave arm will mirror the motion of the master arm with different mirror fatigue coefficient for every joint.

V. EXPERIMENT

A. *Experiment setup*

In this study, two Cyton Gamma 1500 robot arms are selected to build the dual-arm robot [22]. Within YARP (Yet Another Robot Platform) to build the control system architecture [23]. The two robot arms are mounted on the table with same direction. Based on the mechanical character, we set $MA\{0,2\}$=1.5/$A\{0,2\}$, and the others as 1/ $A\{i\}$, The software packages (such as inverse kinematics solver, etc) to control movement of the master robot are contained in YARP framework as YARP nodes. The slave robot only associated with a YARP node with the basic joint motor controller. Different MNS are also connected with YARP nodes. YARP server is responsible for the communication among different nodes with *TCP/IP* or broadcast methods in *Windows XP* 64 bit operation system. A scenario about object manipulation is pre-arranged with several actions run by the robot to validate the proposed control method. The whole system setup is shown in Fig.5.

Figure 5. System setup for object manipulation

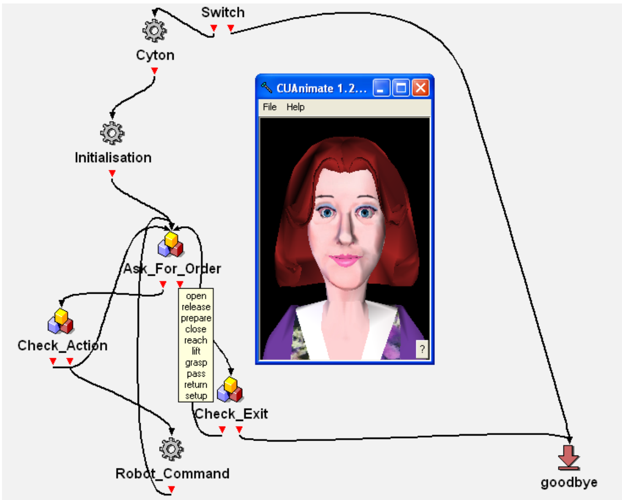


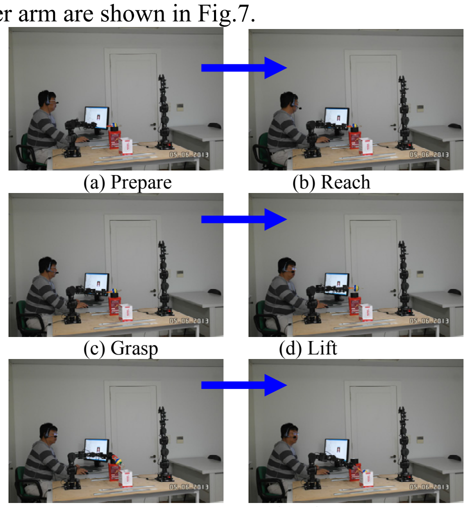
Figure 6. Human robot speech recognition and motion interaction interface

RAD (Rapid Application Developer) is also adopted to develop of the HRI-based GoalGenerator and the speech recognition interface [24], as shown in Fig.6. The speech command will fire the corresponding mirror neuron through robot command knot *Ask_For_Order* to generate the motion command to control the robot to move.

B. Symmetrical motion knowledge generation

In this study, we focused on how to use the mechanism of MNS to realize the motion control of the robot arm. We use the HRI function to teach the master robot to find a good posture to execute the given motions.

Human as an instructor define the action, and use the Zero-torque function to teach one robot find suitable posture, and generate the other related information, together with the given action name to be stored in the robot memory. In this scenario, the motion knowledge for "prepare", "reach", "grasp", "lift", "pass", and "release" are generated and stored in the memory. These sequence demos of above motions of the master arm are shown in Fig.7.

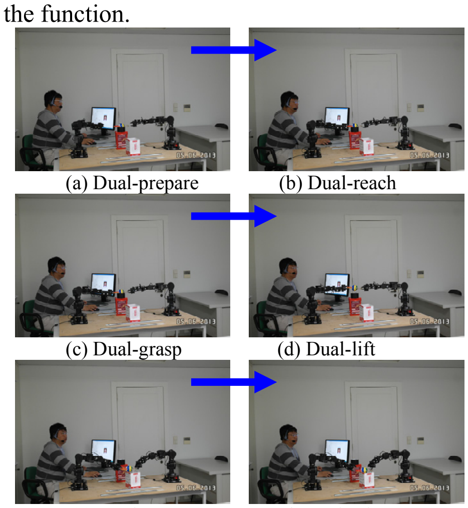


(a) Prepare (b) Reach
(c) Grasp (d) Lift
(e) Pass (f) Release

Figure 7. Motion sequence demos of master arm

C. Symmetrical motion execution demo

Based on the knowledge in section V.B, a demo to move the object with dual-arm is implemented with different speech command stimulus from the human. The results are shown in Fig.8.Here in order to distingue the action from one arm and dual arm motion, human use "dual-prepare", "dual-reach", "dual-grasp", "dual-lift", "dual-pass", and "dual-release" speech command as the stimulus to drive the two arm to realize the function.

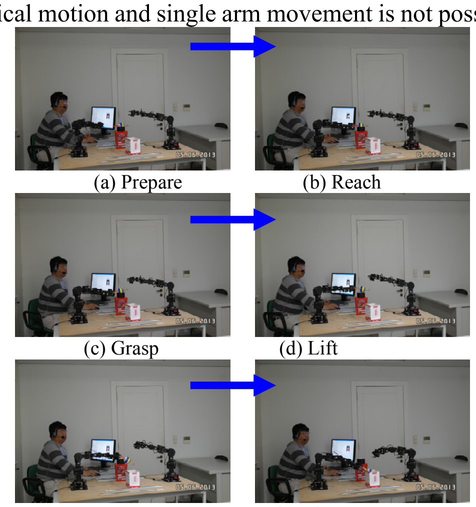


(a) Dual-prepare (b) Dual-reach
(c) Dual-grasp (d) Dual-lift
(e) Dual-pass (f) Dual-release

Figure 8. Symmetrical motion sequence demos of the two arms

D. Mirror movement execution demo

For a child or an adult, the high level command to move the arm will cause the other arm move with a mirror action. The reason from the function viewpoint is that it does not have the PVC and MA connection. If in that case it means the symmetrical motion and single arm movement is not possible.



(a) Prepare (b) Reach
(c) Grasp (d) Lift
(e) Pass (f) Release

Figure 9. Mirror movement sequence demos of the two arms

The similar mirror movement also can be found in a normal adult when he/she fells quit fatigue. In this study, based on the same scenario, a mirror movement, as shown in Fig.9, is also developed here to show the mirror movement which is activated by fatigue effectors. Here we set fc=30, and the mirror coefficient A for the joints is 0.85. It means that after 30 motions of one arm executed, the mirror movement of another arm will occur.

VI. CONCLUSION

A MNSM-based controller was developed for the motion planning and execution of dual-arm robot. The controller includes the function of high-level and low-level mirror neuron system. Effective symmetrical motion is expressed as knowledge, and associated with a vocabulary stored in memory. Low-level MNS is based on master/slave protocol to decompose the control signal and transfer it to slave through mirror neuron mechanism to realize the movement.

Speech as a high level mirror neuron system stimulus will fire the corresponding symmetrical motion knowledge in the memory. The indexed knowledge will fire the corresponding low level mirror neuron in the master arm. By decoding the action information, it generate the signal to control the motion, and its activity together with the modulation information of the symmetrical action to fire the MNS to generate signal to control the slave arm.

The demo scenarios with a series of final-posture related motion and whole-process related motion were carried out by symmetrical motion control to show the validation of the proposed control method.

Compared to those published paper previously, this work firstly using robot with fatigue coefficient function represents the process that the mirror movement in normal individuals during marked physical activity or with severe fatigue and it also point out the mirror movement dieses can occur when the MNS misses the *MA* and *PVC* link.

This study provided a new method not only to realize the dual-arm robot symmetrical movement where the motion planning problem was decreased as the number of DOF of one single arm, but also to understand the mechanism and its function of mirror neuron system in our body.

In the future, together with the vision system we will try to build the MNS model to realize action recognition and object localization and manipulation function autonomously.

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