About My Bachelor Thesis: Human-Robot Cooperative Task Execution

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***Abstract*— This is the document for RINKO in Creative Imformatics Department, The University of Tokyo. My bachelor thesis and my recent works are introduced in this paper. I have been working on cooperative works between a human and a humanoid robot in a household environment. One of the difficulties in such tasks is that the flexibility of executing tasks and the autonomousity of the robot actions have to be ensured at the same time. We tackled this difficulty by decomposing cooperative works into two layers: local action generation and global transitions between those actions. In the former, the robot acquires its motions based on human imitation. In the latter, the robot switches its motion according to the human instructions. The effectiveness of the proposed system is shown in the conducted experiments.**

I. Introduction

Daily life assistance is one of the important missions for service robots. Especially, when the human tends to execute some tasks that are troublesome to perform alone due to the limitation in reachability or load, the humanoid robot that has a human-like body structure can be a great partner for the human. In this research, as the typical tasks where one needs other's help, we work on the manipulation tasks of both large rigid and flexible objects, and aim at the acquisition of the ability for humanoid robots to accomplish various manipulation tasks in cooperation with humans.

In the daily life environment, there are a wide variety of works needed to be done. One of the difficulties in such cooperative works between a human and a robot is that the robot is expected to take actions autonomously according to what the human wants the robot to do. In this research, we deal with this difficulty by decomposing cooperative works into local action generation and global transitions between those actions (Fig.1).

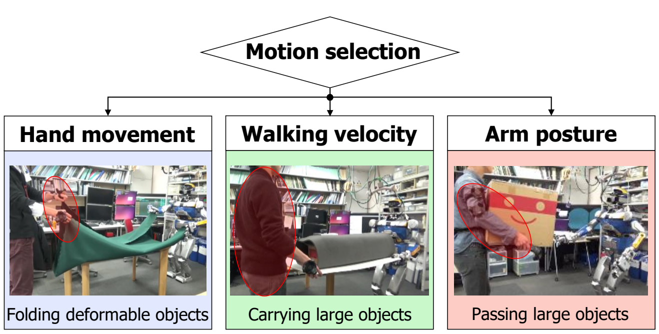

Fig. 1: Proposed system in this paper. The autonomousity and the flexibility are expected with combining local action generation based on human motions and global transition between those actions with human aural instructions.

II. Human Motion Based Robot Motion Generation

In this research, we take human motions into account to decide robot motions with imitating them. According to the motion feature in each task, we sort the tasks in 3 classes – manipulation i) by moving hands, ii) by walking, and iii) by holding with whole upper body – and prepare the robot motion based on those human motion feature in each class. The methods to acquire the robot motions in each class are described in Sec.II-A, Sec.II-B and Sec.II-C separately.

A. Object Operation based on Hand Movement

In situations of cooperative works where a human and a robot manipulate the same object at the same time with facing each other, we propose that the robot end effectors' coordinates can be decided by observing human hand motions and imitating them symmetry. Fig.**??** illustrates the reference frames and naming convention used in the rest of this paper.

$$\begin{pmatrix} {}^{f}x_{h}^{rbt} \\ {}^{f}y_{h}^{rbt} \\ {}^{f}z_{h}^{rbt} \end{pmatrix} = \begin{pmatrix} {}^{f}x_{h'}^{hmn} \\ -{}^{f}y_{h'}^{hmn} \\ {}^{f}z_{h'}^{hmn} \end{pmatrix}, \tag{1}$$

$$\begin{pmatrix} {}^{f}\alpha_{h}^{rbt} \\ {}^{f}\beta_{h}^{rbt} \\ {}^{f}\gamma_{h}^{rbt} \end{pmatrix} = \begin{pmatrix} -{}^{f}\alpha_{h'}^{hmn} \\ {}^{f}\beta_{h'}^{hmn} \\ -{}^{f}\gamma_{h'}^{hmn} \end{pmatrix} \tag{2}$$

$$\text{where} \quad h \cup h' = \{rh, lh\}$$

Here, to decide robot right hand target coordinates, those of human left hand are used. The same can be said for the reversed. We solve Inverse Kinematics with these end effectors' constraints and get the robot angle vector.

Fig.2 shows a short experiment proving that these robot motions work suitably in the task of folding a table cloth by a human and a robot grasping each side of it.

B. Cooperative Carrying Following Human Walking

In case that transportation of the object are needed for executing the task, we also introduced a robot walking motion by observing human velocity and position. In the previous researches, the walking direction or the speed of the robot is controlled by the interactive force or torque [1][2]. Although rigid objects can be carried using those methods, they cannot be applied to carry flexible objects like cloth. To overcome that problem, we introduced a method to generate robot velocity considering human velocity and position as below.

Fig. 2: The experiment of folding a large cloth by a human and a robot.

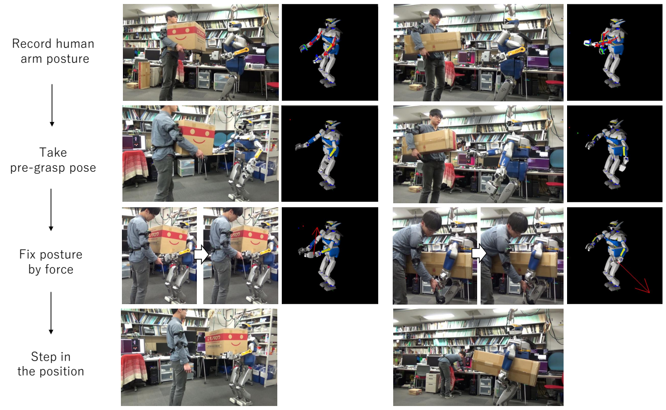

Fig. 3: The experiment of passing boxes from the human to the robot.

$$v^{rbt}_{vel,t+1} = v^{rbt}_{vel,t} + f_{vel}(v^{hmn}_t) \tag{3}$$
$$v^{rbt}_{pos,t} = f_{pos}(x^{hmn}_t - x^{hmn}_d) \tag{4}$$
$$v^{rbt}_{real,t} = v^{rbt}_{vel,t} + v^{rbt}_{pos,t} \tag{5}$$
$$\text{where} \quad v^{hmn}_t = \frac{x^{hum}_t - x^{hum}_{t-\Delta t}}{\Delta t}$$

$v^{rbt}_{vel,t}$ and $v^{rbt}_{pos,t}$ represent the generated robot velocities considering the human velocity v^{hmn}_t and the human position x^{hmn}_t compared with the desire position x^{hmn}_d. $v^{rbt}_{real,t}$ represents the robot velocity applied to the real robot.

Eq.3-Eq.5 can be simplified to the equation below.

$$\Delta v^{rbt} = v^{rbt}_{real,t+1} - v^{rbt}_{real,t} \tag{6}$$
$$= K_p(v^{hmn}_{abs} - v^{rbt}) + K_i \sum (v^{hmn}_{abs} - v^{rbt})\Delta t \tag{7}$$

This can be recognized as a PI controller to let the robot velocity match the human velocity giving proper parameters K_p and K_i.

Finally, the aural instruction of the direction by the human is combined. Which direction to move can be decided by the human and announcing it, robot can start moving with the velocity generation explained above.

C. Passing Large Objects based on Arm Posture

In order to carry large objects, we need to use whole upper body including arms. When passing those objects from a human to a robot, the robot can watch how the human holds them and regard those postures as suitable ones to hold the objects. We get the positions and orientations of human 7 points (shoulders, elbows, hands and torso) to reconstruct the human posture carrying the object, and apply them to the robot to make the similar posture to the human. However, passing objects cannot be succeeded only by it. We take a mean of fixing robot posture by human teaching in order for the robot to hold the objects stably.

Fig.3 shows the snapshots of the experiments passing large boxes from a human to a robot. First, the robot takes an pose acquired by considering human holding pose. Then, with human fixing the robot posture by force and voice, the human-robot object passing is executed, finally the robot stepping in the position with holding the boxes.

III. Motion Selection based on Human Signs

We construct a rule-based reaction system for a human user to activate the robot action described in the previous section. Preparing some sets of keyword and associated robot motion, the human can make the robot move with considering what action he/she wants the robot to take and how it can be realized combining the prepared rule-based actions. Using the rule-based commands, we combine the robot manipulating motions described in Sec.II-A and the walking motions described in Sec.II-B in parallel and enable them to be activated repeatably as shown in Fig.4.

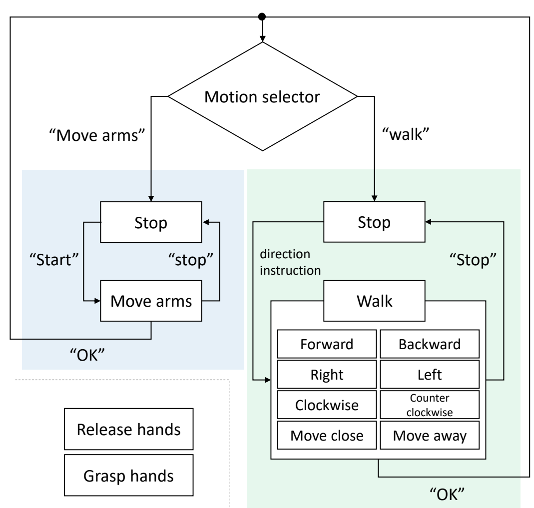

Fig. 4: The state flow to execute several cooperative works. The states colored blue are the motions explained in Sec.II-A, and the the states colored green are the motions described in Sec.II-B. Lining up these motions parallelly with using aural interactions, continuous task execution can be realized.

IV. Sequential Task Execution Experiment

We conduct a sequential experiment supposing the situations in a household environment. Fig.5 shows the snapshots of the experiment. Spreading a cloth, wrapping a box with the cloth, carrying the box and a board are executed, activating each local motion with the human aural commands in order.

Fig. 5: The experiments applying the proposed system. Spreading a cloth, wrapping a box with the cloth, carrying the box and a board are executed. Blue shaded parts and the green shaded parts represent the parts using the local motions described in Sec.II-A and Sec.II-B respectively.

V. Conclusions

In this study, we worked on the human-humanoid collaborative works manipulating large objects that will be hard to be executed by one. To realize various tasks in a series of household chores, the robot has to acquire flexible motions that are not programmed for a certain task. We took an approach to meet that expectation by taking human motions into account for the robot motions. Eventually, enabling those motions be activated selectively and continuously based on the human instructions, tasks can be finely executed in which the order between the included processes is random. Our contributions are mainly based on the decomposition of the cooperative works into the local action generation and the global transition framework. The sequential task experiment in this research confirms that this system can perfectly work in human-robot collaborative works in the household environment where the human has the initiative and wants the robot to be an obedient assistant.

References

[1] K. Yokoyama, H. Hanade, T. Isozumi, Y.Fukase, K. Kaneko, F. Kanehiro, Y. Kawai, F. Tomita, and H. Hirukawa. Cooperative works by a human and a humanoid robot. In *IEEE International Conference on Robotics and Automation*, Vol. 3, pp. 2985–2991, 2003.

[2] J. Stückler and S. Behnke. Following human guidance to cooperatively carry a large object. In *IEEE-RAS International Conference on Humanoid Robots*, pp. 218–223, 2011.