Motion generation of the humanoid robot for teleoperation by task model

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***Abstract*— In recent years, the research of humanoid robots that replace human tasks in emergency situations have been widely studied. Currently, many approaches are automate dedicated hardware for each mission. But, at the environment where situation changes, operation by humanoid robot is effective to operate equipments which designed for human. Ultimately, automation is ideal, but under the present circumstances, teleoperation of humanoid robot is effective for corresponding changes of situation.**

An intuitive interface is required for effectively controlling the humanoid robot from a distant place. Recently, the interfaces that map the human motion to the humanoid robot have become popular because of the development of the motion recognition systems. However, the humanoid robot and human beings have different joint structure, physical ability and weight balance. It is not practical to map the motion directly. There is also the issue of time delay between the operator and the robot. Therefore, it is desirable that the operator performs global judgments and the robot runs semi-autonomously in the local environment.

In this paper we propose a method to remotely operate the humanoid robot by the task model. Our method describes human behavior abstractly by the task model and mapped this abstract expressions to humanoid robots, and overcome difference of structure of body. In this work, we operate lever of buggy-type vehicles as a example of mapping using the task model.

I. INTRODUCTION

In recent years, the research of a humanoid robot that replaces human tasks in emergency situations has been widely studied[1][2]. At a time when a disaster occurs, the rapid deployment of robots is required. Many approaches were automate dedicated hardware for each mission, but development of new robots designed dedicatedly for each task and environments takes long time. On the other hand, the humanoid robot can utilize the equipment that is designed for human. It would be extremely valuable if the humanoid robot could work in such emergency situations on behalf of the human (Fig. 1). Ultimately, automation is ideal, but under the present circumstances, teleoperation of humanoid robot is effective for corresponding changes of situation.

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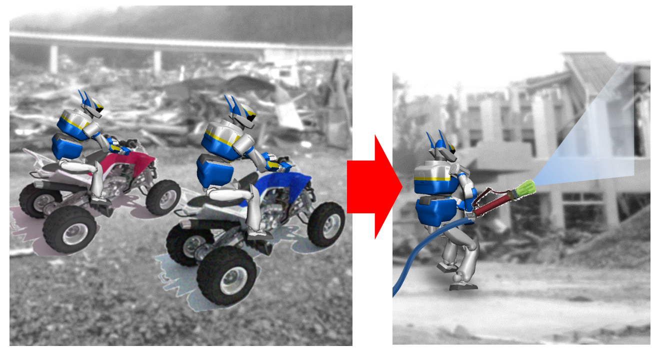

Fig. 1. Teleoperation of humanoid robot in emergency stuations

We need an intuitive interface to effectively control the humanoid robot from a distant place. Telexistence systems for immersive control provide highly realistic operating environment by using Virtual Reality (VR) techniques [3][4]. But, the system is generally huge and the human motion is limited by mechanical structures. The interfaces that capture the human motion by using vision sensors have been recently studied [5][6][7][8]. The RGB-D camera becomes widely available and can be used for capturing the human motion without mechanical sensing. A real-time human imitation system for biped robots has been developed. However, since the humanoid robot and the human have a different joint structure, physical ability and weight balance, it is difficult to map the human motion directly to the robot.

Teleoperation has the potential issue of time delay between the operator and the robot. The operator cannot recognize the state of the robot and environment at the same moment. Human motion is not fluently reflected in the robot motion. That is, the intuitive operation of the robot is difficult by such interfaces. To avoid the time delay, it is desirable that the operator provides global directions and the robot run semi-autonomously. Moreover, even if the human motion can be accurately recognized and transmitted, the robot needs adjustment of the motion according to the state of the robot itself and the target object.

In this paper, we describe a method to generate robot motions for vision-based teleoperation systems using the task model [9]. Operator's motion is recognized from observation by no contact sensing. Operator's motion is recognized as abstract information (task), and task is transmitted to robot. Robot executes the motion mapping depending on the actual equipment of the robot. At this time, tasks which required for the equipment are classified, and skill parameters are

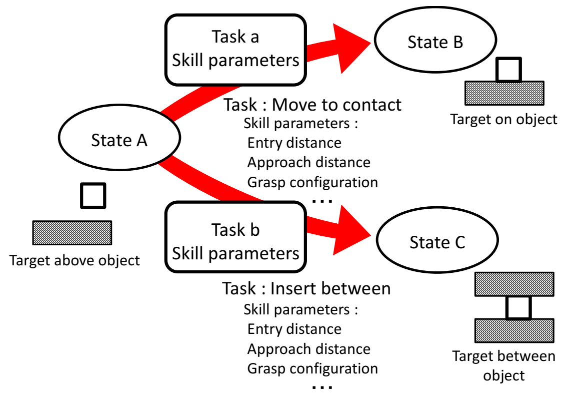

Fig. 2. Definition of task model [9]

designed for each task. The skill parameters for generating the robot motion is estimated by considering the target structure and the contact state with the tactile sensors in the robot.

Here, we assume that the target operation is driving a four-wheel buggy. Because driving buggy needs real time operation, and time delay is a major issue. Considering the remote location, the buggy-type vehicle is suitable for target because of it's run through performance. The tasks which required for driving are steering wheel, acceleration and brake levers. We demonstrate the generation of the motion of robot hands to operate the controls through the network.

II. RELATED WORK

Learning-from-observation is known as a technique for generating robot motions from human motions while eliminating the physical differences between the human and robot [9][10][11]. Learning-from-observation describes a human motion by tasks and skill parameters: "what to do" and "How to do". Fig. 2 shows the overview of the task model. To recognize the human motions by the task model, the states of the target and its transitions must be extracted. The operation of a state transition is called task. To execute the task, the parameters for moving the robot are required. Example parameters include the inner state of the robot and the state of the target object. These parameters are called skill parameters.

Ikeuchi and Suehiro proposed the learning-from-observation paradigm and applied the paradigm in producing robot motion for assembly works from the observation of human operations [9]. The states of the target objects are classified and described by the state of face contact. A motion template for the robot arm is prepared for each state transition. The proposed system succeeded to assemble the polyhedral objects by using the task model.

Nagata et al. proposed shared autonomy system by task instruction in the work space [10]. The Object Template Model and Task Space Model are defined for describing the work space model. In this system, the user recognizes the object type and its state in the environment. The user instructs a robot to execute the task of picking an object by selecting a task model according to the object type and situation.

The skill parameters need to be adjusted according to the states of the robot and target objects. Suehiro et al. has proposed a vision-based method for adjusting the skill parameters [12]. The system aims to enable robot assembly work by estimating the motion from the observation of human work by visual systems. The method corrects the motion parameters according to the face contact when the tasks are executed.

A teleoperation system considering time delay using VR environment has been proposed [13][14][15]. The method separates the entire teleoperation feedback loop into operator-VR feedback loop and VR-robot feedback loop. The system is stably controlled by satisfying the loops independently. Thus, the system does not lose the control because of time delay.

This paper proposes a method to utilize VR space for visualizing the states of the robot and the environment for teleoperation of humanoid robot for the learning-from-observation paradigm. Here, the recognition results are displayed for visual feedback for the human operator in VR space. The task model is used for extracting tasks, what-to-do, from the human motion for teleoperation. Then, the recognized tasks are converted to the robot motion while avoiding physical differences and time delay for teleoperation. We assume that rough skill parameters for each task are given before execution. But, the parameters need to be adjusted during execution because of mechanical errors or vibrations of driving. The skill parameters are re-estimated by the feedback of tactile sensors and the prior knowledge of the structure of the target objects. The robot motion is generated from the task and the estimated skill parameters. The contribution of this paper is to design of skill parameters and generation of robot motion for teleoperation of humanoid robot using the task model.

III. TELEOPERATION INTERFACE

A. Teleoperation by task model

In the teleoperation using task model, the operator's motion is recognized as a task, and transmitted to the robot as an abstractive indication. Set of skill parameters is needed to execution of robot motion for each task. The skill parameters for the task are estimated on the robot side by using sensor information and prior knowledge of the target structure. That means the operator controls the remote robot semi-autonomously.

Figure 3 shows the overview of the teleoperation system using the task model. The operator is provided environmental views from the robot by vision systems through VR space. The operator controls the target object in the VR space. Then, the task is recognized by observing the human motion and transmitted to the remote robot. The robot generates the motion from the given task and skill parameters.

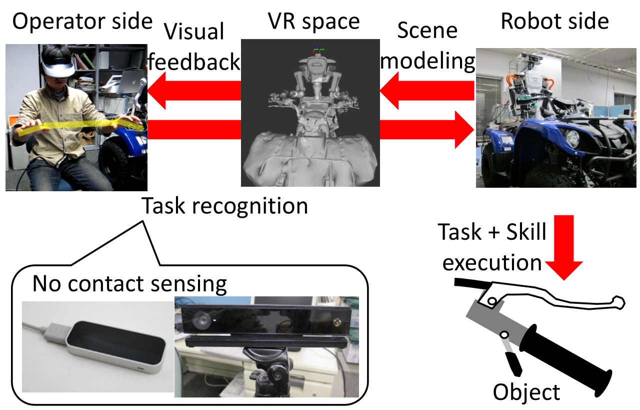

Fig. 3. Teleoperation of humanoid robot by task model

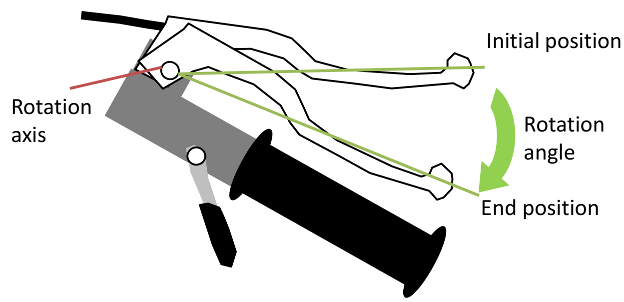

Fig. 4. Mechanism of brake lever

B. Task recognition

The task is recognized by extracting the state transition in the human motion. For example, the brake operation is represented by gripping the lever. The gripping state can be estimated by hand gestures. The gripping task or releasing task is executed by the state transition of opening or closing the hand.

The human motion is observed by vision-based sensors and is analyzed to find the transitions. Recently, motion capture systems based on low cost depth-sensing cameras such as Kinect and LeapMotion are widely available. The relative positions of body parts and fingers can be measured with reasonable stability. Moreover, these cameras require no contact and are small enough to bring anywhere. That is, the interface for teleoperation of the humanoid robot can be easily and rapidly constructed.

IV. Motion Generation

A. Design of skill parameters

The spatial parameters of the target object are required for generating the robot motion from the task model. These spatial parameters are the skill parameters. The skill parameters are estimated for each task. The parameters represent the movement of the target object from one state to another.

The position and the operation amount information of the target is required as skills parameters, in addition to the position and orientation information of the robot. There is a method such as simulation by the models of target or mounting sensor to the target. But there are not appropriate from the reason of errors due to vibration during running and policy to use existing equipment. Therefore, finger operation executes by using a tactile, as human performs an operation in the sense of the fingertips. A rough trajectory is given in advance, and modifies trajectory depending on the contact state.

B. Acquisition of skill parameters

Generally, the operation of tools that are designed for humans can be simply described by translation and rotation. For example, the handle operation can be described by rotation with center axis. Pushing a button is described by translational movement. The skill parameters are represented by simple motion parameters.

As shown in Fig. 4, the lever movement is described by rotation angle in one degree of freedom with one axis. The lever movement can be modeled as the following parameters.

- Position and orientation of rotation axis
- Lever length
- Initial position of lever
- Rotation angle

Fig. 5 shows a complete task model of the brake lever operation.

Task

Lever operation

Grip lever

Skill parameters

- Position and orientation of rotation axis
- Length from rotation axis
- Initial position of lever
- Rotation angle

Fig. 5. Task model of lever operation

C. Trajectory generation

The trajectory of a fingertip is generated from skill parameters. As described above, we assume that rough skill parameters can be previously given. The trajectory is directly generated from the rough parameters. However, it does not work well because the state of the target object dynamically changes because of the vibration of the body and the change of contact states.

Thus, the trajectory must be adjusted according to the relative states of the target object and the hand (Fig. 6). For estimating the relative positions and contact states, the tactile information is used. The finger is moved so as to contact the center of the fingertip to the lever. The position of the fingertip is sequentially controlled by calculating the destination point at each control period.

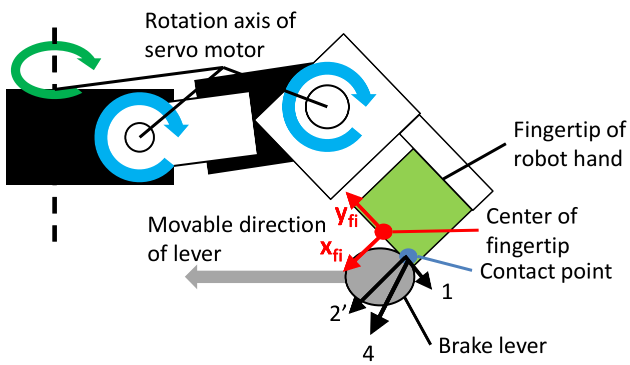

Fig. 6. Generation of fingertip trajectory

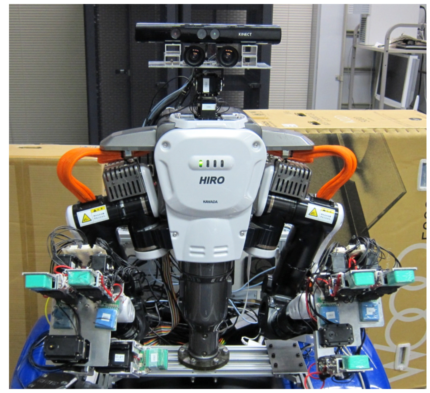

Fig. 7. Teleoperation robot

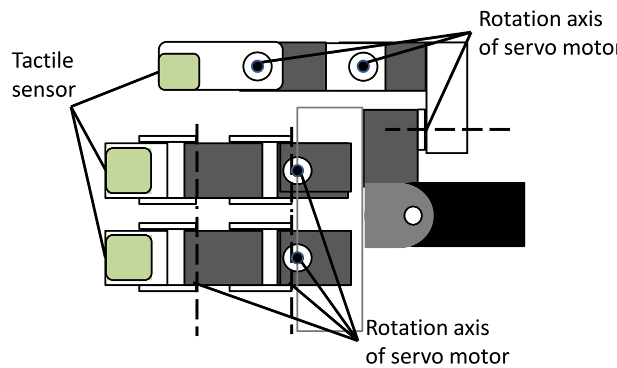

Fig. 8. Model of robot hand

It is also required to maintain the contact state between the fingertip and the lever. The lever also needs to be moved to the correct rotation axis. The contact state is maintained by friction force between the surfaces of the fingertip and the lever. The lever sometimes deviates from the fingertip because of the unexpected movement of the body. Therefore, the trajectory has to be generated while keeping the stress of the fingertip to the lever.

The procedure of generation of fingertip trajectory is as follows:

1) Set the amount of movement to modify contact position. (The amount of movement of direction parallel to the y_fi in Fig. 6)
2) Temporarily set the amount of movement for vertical direction of fingertip. (The amount of movement of direction parallel to the x_fi in Fig. 6)
3) Adjust the amount of movement 2 as sum of 1 and 2 has positive magnitude to movable direction of lever (2→ 2’).
4) Estimate the destination point of fingertip position by integrating 1 and 2’.
5) Move the fingertip to position 4.

V. IMPLEMENTATION

A. Humanoid robot

1) Upper body: Upper body humanoid robot HIRO(Kawada industries, inc) is used for teleoperation robot, Fig. 7 shows our teleoperation robot. Currently, the robot does not have a lower body, and is fixed on the seat of the four-wheel buggy. Two cameras are mounted on the head. The view from the robot eyes is sent to the operator through network. The head moves synchronizing with the human head motion taken by a 6DOF motion sensor.

2) Robot hand: The robot hand consists of three fingers. Each finger has three degrees of freedom. Fig. 8 shows the model of the hand.

A tactile sensor, ShokacCube(Touchence Inc.), is attached on each fingertip. ShokacCube is covered with a flexible sponge exterior and measures the amount of deformation of surface shape. A point with largest deformation is estimated by fitting a spline curve on the surface deformation.The largest deformed point depicts the contact point. Fig. 9 shows an image of calculation of contact point.

The force applied on the finger is provided as torque of servo motors which configure the robot hand. The torque is computed by the ratio of the current output to the maximum output of the servo motor.

B. Task recognition

1) Brake task: The brake operation is recognized by a gesture of the hand. LeapMotion is used for capturing the finger motion [16]. Opening or closing the hand is recognized by the relative positions of the fingers. The task of gripping the brake or releasing the brake is executed by the state transition of opening or closing the human hand. Fig. 10 shows a diagram of the state transition and task recognition.

C. Motion generation

We assume that the structure of the buggy has been previously acquired, and rough positions and movable directions of the handle and brake lever are known. The position of the rotation axis and the length of the brake lever are also assumed to be known. The states of the brake lever are assumed to be simply ”Gripped” and ”Released”. The skill parameters for the operation are as follows.

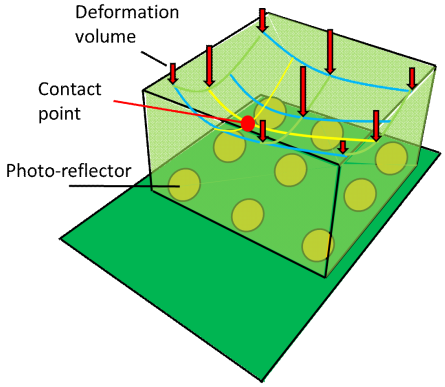

Fig. 9. Estimation of contact point

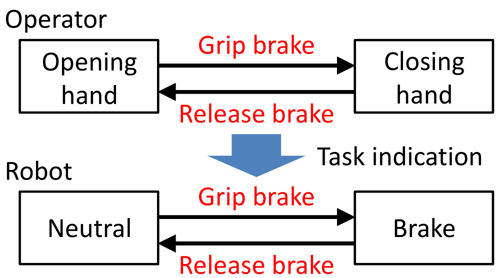

Fig. 10. State transition and task indication

- Initial position of brake lever
- Movable direction of brake lever

The motion of brake operation is generated by the following procedure. Please refer Fig. 6 for details.

1) The amount of movement in the direction parallel to the contact surface is calculated from the distance between the fingertip center and the contact position. (The amount of movement of direction parallel to the $y_f i$ in Fig. 6) This distance is called fingertip deviation.
2) The amount of movement in the direction perpendicular to the contact surface is calculated from the integration of appropriate constants and coefficient k for the fingertip deviation. (The amount of movement of direction parallel to the $x_f i$ in Fig. 6)
3) Integration amount of movement 1 and 2 which is parallel to lever axis is calculated from the rotation angle of the servo motors. The coefficient k is adjusted so it is positive.
4) The destination position of the fingertip is determined from 1 and 2'.
5) The fingertip is moved by solving the inverse kinematics.

By repeating steps 1 through 5 sequentially, the fingertip trajectory is generated.

The end of the operation is judged by the force applied to the joint of the finger. When the load torque is greater than a certain threshold, the gripping operation is stopped.

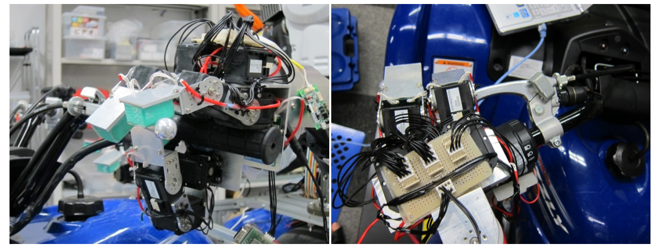

Fig. 11. Initial position

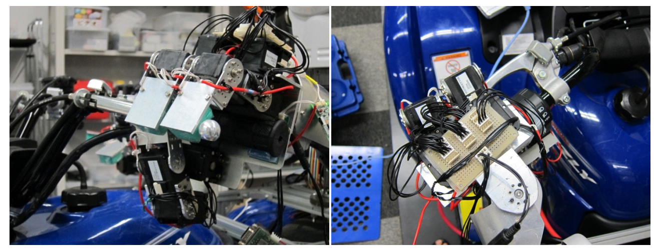

Fig. 12. Success case of brake operation

The brake lever operation is executed by using two fingers: index and middle fingers. The accelerator operation can be also performed in the same way.

VI. EXPERIMENT

In this experiment, we checked whether the brake operation can be performed stably by the proposed method. In the initial state, the fingertip is lightly put on the brake lever. We assumed that the operation has succeeded when the lever has reached the end of the movable range.

In addition, we execute the experiment of accelerator operation. The initial position of the accelerator operation, position is slightly separated from the lever in order to prevent erroneous operation.

A. Experimental result

The operation failed 3 out of 10 times. Generally, the middle finger succeeded in holding the brake well. On the other hand, the generation of the trajectory of the index finger sometimes failed. That is because the destination of the fingertip position goes outside of the movable range in some handling positions. In this case, the brake operation was executed by the middle finger only. The lever could not reach the end position due to the lack of torque for gripping lever. Accelerator operation failed 2 out of 10 times. That is because the fingertip is conflict to palm unit.

Figure 11 shows an initial position of hand. Figure 12 shows an example of successful brake operations. Figure 13 shows an example of failed cases.

B. Discussion

The cause of the failure to generate the trajectory of index finger is that the position of the lever moves out of the movable range of the finger while gripping the lever. There are two solutions for this issue.

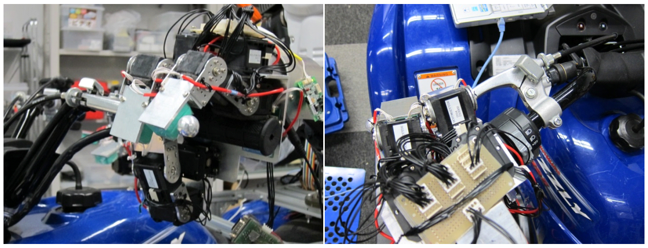

Fig. 13. Failure case of brake operation

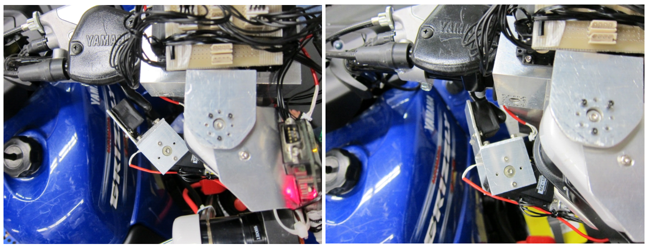

Fig. 14. Initial position and result of acceleration operation

1. The first method is using the arm motion in addition to the finger motion for the brake operation. The robot can pull the arm toward the body while bending fingers; the brake lever is pulled by the arm.

2. The second method is re-grasping. The hand position is adjusted so that the movable range of finger covers the range of the brake lever. It is easily performed by changing the hand orientation around the y-axis. Humans often perform the re-grasping operation while driving the buggy.

In this paper, as an experimental of design and execution method of operation, we execute operation in a static environment. In order to confirm the advantages of our teleoperation system, it is necessary to carry out experiments under vibrations during driving, in addition to the delay and loss of communication.

VII. CONCLUSION

This paper proposed a method to remotely operate the humanoid robot by the task model. The method generates the trajectories of robot's fingertips by considering the structure of the target object and contact states with the fingertips. The lever operation for driving a four-wheel buggy had been implemented and tested on the humanoid robot with a three fingered hand. From the experimental results, it is found that adjusting the hand position rather than the fingers, is important to stably control the lever operation. In future work we plan to develop a method to simultaneously generate the motions of fingers, hand, and arm, by considering their movable ranges.

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