

Paper:

# Human-Robot Cooperative Handling Using Variable Virtual Nonholonomic Constraint

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In proposing variable nonholonomic constraint for cooperative human-robot handling, we deal with nonholonomic wheel movement manipulated intuitively by the user. We propose implementing virtual nonholonomic constraint in robot grasping, enabling users to transfer objects, similar to using a wheelbarrow, without slipping. Transporting objects accurately in a fixed constraint point requires skill, so we propose preparing multiple constraint points to be selected based on the situation. We apply this to a mobile manipulator, confirming feasibility experimentally.

**Keywords:** assist system, human robot cooperative task, mobile manipulator, nonholonomic

## 1. Introduction

In line with growing interest in human-robot cooperation, we propose mobile power-assist control [1, 2] and cooperative human-robot manipulation for handling unwieldy objects, such as shown in Fig. 1. A user and a robot grasp opposite ends of a long object and cooperate in moving it based on force applied by the user [3]. In a takeoff on the adage, “two heads are better than one,” we propose that “more hands are better than few” when handling unwieldy objects. Efforts by a user and a robot working together are likely to be more efficient than either of the two working alone, as also shown in Fig. 1. Our study focuses on such cooperative handling to construct a control law using a force sensor on the manipulator hand, arm joint angle sensors, and positioning information from a mobile base. We added virtual nonholonomic constraint to a robot to enable it to imitate wheel-like movement virtually based on force applied to an object and the positioning relationship between the object and robot to prevent the object from slipping and to improve operability [3]. We achieved reachability, three-dimensional positioning, and attitude determination in spite of a decrease in degree of freedom (DOF) caused by constraints. Our method requires a human to operate virtual nonholonomic system that simulates the movement of a wheelbarrow. Although operators use a wheelbarrow easily, they often have diffi-

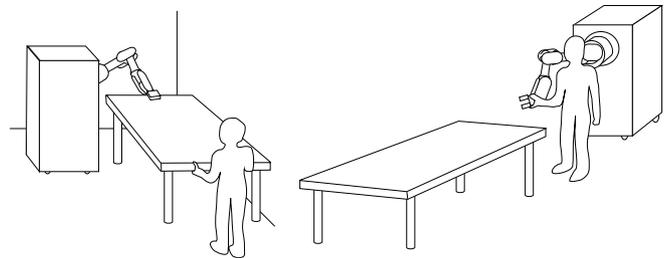


Fig. 1. Cooperative human-robot transport.

culty in path planning due to virtual nonholonomic constraint conditions. In conventional cart and wagon use, we easily determine location by raising a wheel to create temporary constraint conditions and by changing the constraint conditions. This article deals with the application of instrumental handling to robot operation and demonstrates our proposal's implementation and effectiveness through cooperative handling experiment using a mobile manipulator.

Cooperative human-robot handling includes the use of impedance control to move objects in intended directions [4–7]. In contrast, we considered that in handling lengthy objects a force transmitted to the hand of the robot through the object was a translational force and proposed a method that gave virtual nonholonomic constraint to the robot [3]. The constraint conditions concept has been used in a mobile power-assist base. An undriven transport system called Cobot [8, 9], uses a servomotor on a wheel for steering, with the steering angle controlled based on environmental information, controlling the direction of travel and assisting in object handling. Hirata et al. adjusted impedance parameters in large object handling using multiple passive robots to achieve virtual nonholonomic constraint in handling [10].

To facilitate virtual nonholonomic constraint use, we propose cooperative handling changing constraint points to take advantage of virtual nonholonomic constraint in flexible handling. This paper is arranged as follows: Section 2 presents preliminary experiments using a simulation screen to verify whether users accept the control law and variable constraint conditions for proposed vari-

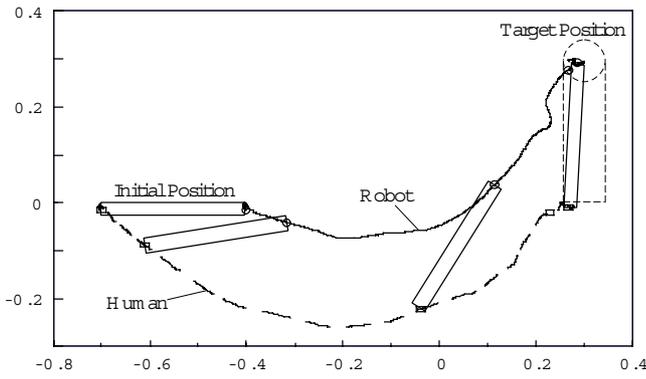


Fig. 2. Impedance control in object trajectory.

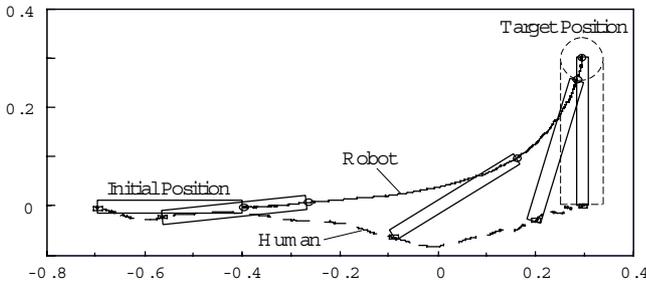


Fig. 3. Object trajectory in virtual nonholonomic constraint.

able constraint cooperative handling. Section 3 details the hardware configuration for implementing our proposal for a mobile manipulator and mobile manipulator control. Section 4 explains a human-mobile manipulator cooperative object handling experiment confirming the feasibility of our proposal.

## 2. Cooperative Handling Using Variable Constraint

### 2.1. Change in Virtual Nonholonomic Constraint

Conventional virtual nonholonomic constraint facilitates human-robot cooperation by constraining slip due to inertia when a heavy or long object is handled to realize an operation as easy as using a wheeled cart or barrow. Figs. 2 and 3 show results of experiments [3], in which trajectories and targets are compared for isotropic impedance control and virtual nonholonomic constraint given to the point grasped by the robot. The object is a 30 cm hollow aluminum square bar held at each end held by a test subject and a robot facing each other. In handling with isotropic impedance control, an experiment subject securely grasps the object using sufficient torque. The object is short enough to relatively easily obtain robot force information via torque operation. Experiment results showed unstable handling trajectories in isotropic impedance control and poor positioning accuracy because isotropic impedance control requires translation and torque to control the object's positioning. It is difficult to halt the object at the desired location. In impedance control applying virtual nonholonomic con-

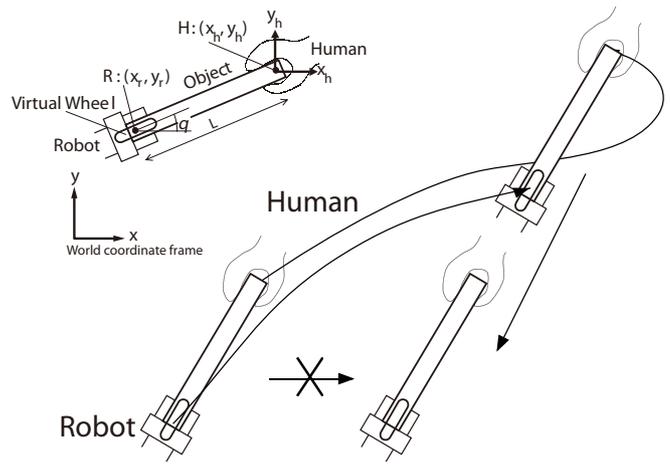


Fig. 4. Example of nonholonomic movement.

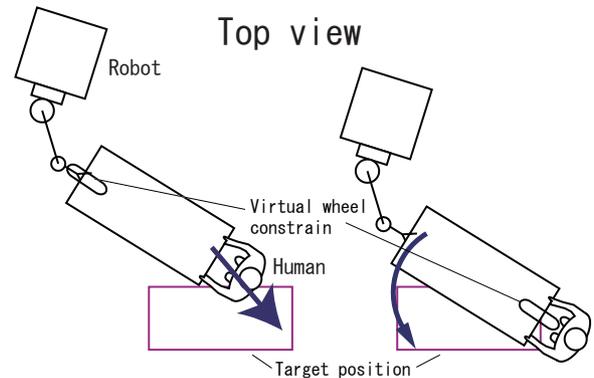


Fig. 5. Constraint point change concept.

straint at the point grasped by the robot, the robot trajectory in relation to the target location is stable and accurately determined at the final target location. Virtual nonholonomic constraint is viewed as difficult to control, but experiment results showed that a subject can perceive and handle robot movement having wheel-like constraint.

This eliminates operational difficulties arising from the object slipping. As shown in Fig. 4, sideways object movement is constrained, so the object cannot move sideways directly – this would require a virtual nonholonomic trajectory plan and operation. Directional movement limitations require complex positioning for the object. Conventional hand barrows and shopping carts have nonholonomic constraints – usually the back wheels. When used, they first move roughly along a nonholonomic trajectory, then rotate using the front wheels while having the back wheels lifted to finely adjust targeting. This indicates that the limitation in constraint position makes operations difficult.

We assumed that imitating such tools in cooperative human-robot handling while enabling the test subject to arbitrarily change a constraint point would enable the subject to plan the object's trajectory easily and move it to the target quickly. A constraint is conventionally fixed to the point grasped by the robot, as shown at left in Fig. 5. This assumes that the point grasped by the robot can be moved easily to the target, by setting the constraint position on