

Iterative Learning Algorithm Design for Variable Admittance Control Tuning of A Robotic Lift Assistant System

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ABSTRACT

The human-robot interaction (HRI) is involved in a lift assistant system of manufacturing assembly line. The admittance model is applied to control the end effector motion by sensing intention from force of applied by a human operator. The variable admittance including virtual damping and virtual mass can improve the performance of the systems. But the tuning process of variable admittance is inconvenient and challenging part during the real test for designers, while the offline simulation is lack of learning process and interaction with human operator. In this paper, the Iterative learning algorithm is proposed to emulate the human learning process and facilitate the variable admittance control design. The relationship between manipulate force and object moving speed is demonstrated from simulation data. The effectiveness of the approach is verified by comparing the simulation results between two admittance control strategies.

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INTRODUCTION

Robots are widely used in industry to perform repeating operation in order to free human operators from the tedious, danger and heavy labor. But there are some tasks that are either complex or interact with complex environment. In these cases, human beings are not replaceable and human-robot interactions (HRI) are inevitable. The design and development human performance enhanced robotic devices are applicable not only to industrial assembling robots, moving/carrying assist devices, but also to areas like medical surgical robots, exo-skeleton etc. The benefit of HRI is to extend the human perceiving and analyzing capability in dealing with the difficult tasks in complex environments. Therefore, the main purpose and challenge of control system design is to make robot manipulation more intuitive for human operators.

The approach of admittance control is often adopted in human-robot interaction control. It has been noticed that the control designed with a fixed pair of virtual mass and damping cannot reach desirable performance of handling. From literature review, it shows that the variation in admittance adapting to operator's speed and force can improve the performance. Variable admittance is defined as the function of human intention. Different parameters are used to represent the human intention, such as force, acceleration, or derivative of acceleration. For example, in [1] the human arm stiffness is estimated from experimental data of force and position of the end effector, then it is designed to adjust the viscosity coefficient of the impedance characteristic in cooperative calligraphic writing task. In another case, both acceleration and speed are applied to an intelligent assist device (IAD) [2]. The acceleration is used to adjust virtual damping in order to moderate the force demand, while the

speed is defined to change the virtual mass for fine positioning. And in other cases, the time derivative of the contact force to assess acceleration and deceleration intention for variable admittance control scheme [3, 4] was proposed to continuously adapt the virtual damping coefficient as a function of the human intention in a speed based variable impedance control for pick, place and moving tasks.

With different admittance parameter functions and combination defined, it becomes difficult to choose and verify for designers. Online verification is necessary the operator must evaluate which one is easier to manipulate for different tasks. Offline simulation could be used to reduce online testing time and risk, but how to emulate the operator's learning capability is a challenging question. Learning methods have been proposed and studied previously to deal with similar situation in literatures. It is pointed out in [5] that it is difficult to determine admittance matrix elements analytically since they depend upon many physical properties, which are not identified easily. One method is to obtain admittance matrix elements through iterative trials of manipulation operation in a single motion. By using iterative learning algorithm (ILA) in admittance parameter adaptation is also studied. For example, the gain scheduling with a reinforcement learning approach algorithm is adopted [6]. The admittance parameters may not fit all situation and environment. The inappropriate admittance parameters design can also cause resonance oscillation in the human-Robot interaction. The authors of [7] use the online fast Fourier transform of the measured manipulator end effector forces in order to detect the oscillations and to adapt the admittance parameters dynamically when the environment is changing. In a power assist wheelchair robot application [8], in order to let the operator get a smooth load feeling, variable admittance based velocity compensation and ILA is proposed to adaptively adjust the control

perimeter to maintain the operator's force at same level. The learning ability is used to sense the changing in load and adjust the virtual damping, while the virtual mass is kept as constant.

In this paper, an iterative learning method is proposed for variable admittance control force verification. In practices, there are different virtual damping and virtual mass functions can be used to interpolate the human intention. The challenge is to verify them one by one and compare the performance via real testing. So the learning ability is then introduced to find the best suitable force profile for a pre-defined speed/position trajectory offline. The intuitive relation between force and speed is then tested and verified with offline simulation data. The online learning capability for admittance parameter tuning is going to be considered in next phase. This offline approach of Iterative learning algorithm design is applied to a five-degree-of-freedom lift assist device. The simulation results are used to calibrate and validate the control algorithm.

A LIFT ASSIST SYSTEM

A lift assist system is built for human operator to pick, move and install vehicle panel in assembly line. A human operator can manipulate the lift assist system with 5 degree-of-freedom in directions of x, y, z, pitch and rotation. The schematic of one channels is shown in Figure 1, to show the control structure of one of the axis of lift assistant system. The safety and speed control are implemented in PLC (Programmable Logic Controller). Human operator apply force onto the handle, by which in response, the controller controls motor to move the whole structure based on the force input. Besides the spring mass dynamic, both the admittance for suitable virtual mass and damping should be considered in control design.

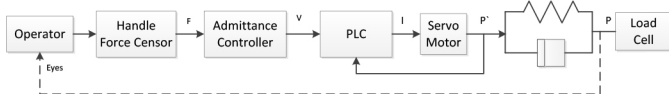


Figure 1. Schematics of admittance control for an axis of lift assist system.

As shown in Figure 1, the safety and speed control are implemented in PLC (Programmable Logic Controller). In the speed loop, the encoder of the servo motor feedbacks the position of toothed serving belt to PLC. The position loop is closed by human operator. The admittance controller is designed to fulfill the human intention of generating the speed command to PLC. Then the PLC sends the speed command to servo drives of the motors. The speed command should present the maximum intuition to the operator in order to move the lift system freely at his will. The stability, smoothness and intuitive operation are main three basic requirements for the system design. To further improve the performance, the accuracy and swiftness are to be fine-tuned for different operators. Because the body and arm stiffness of different people may be different. Human being will be included in the entire positioning loop through eyes. Human being as an actuator with different stepping and arm stiffness will affect the performance of whole motion loop. As the operator's handle is mounded on the side of load cell (end-effector), the handle position represents the system position output in x, y, z, pitch and rotation direction.

ADMITTANCE CONTROL

Both impedance control and admittance control can be applied to human-robot interaction system. The impedance control uses the displacement as system input and force as system output. It is more suitable for light inertia, low friction and force sensitive system, like robot arms, etc. small structural system. On the other hand, the admittance uses force as system input and position/velocity as system output. It is applicable to application with large inertia, high friction, and position targeting system. The contacting force and final positioning of end-effector need to pay more attention in control design.

Admittance control for human-robot interaction is based on the admittance model which can be written as:

$$f_H = m_v(a - a_0) + c_v(v - v_0) + k_v(x - x_0) \quad (1)$$

Where f_H is the force sensing from human operator as the system input, m , c and k are mass, damping and spring coefficient individually, the subscription v indicates the virtual component which is going to be designed and implemented in the interactive system, the subscription 0 represent the system equilibrium points, in which the a , v x are respectively the acceleration, speed and position of the load cell. Since the f_H represents the human intention to move the end-effector of the lift system to the origin of the motion coordination, the equilibrium points at a_0 , v_0 , x_0 are zeros in the above model. Furtherly, it is not possible to measure the desired position which is only existing in human mind minimizing the distance between target point and the load. The position loop is closed by human operator, but not by this lift assist control system. The last term of the admittance model is omitted. So the admittance model for this system design is rewritten as:

$$f_H = m_v \dot{v} + c_v v \quad (2)$$

It is clear to see the system output is speed and input is the force sensing and representing the human intension that how the system need to react to targeting speed and at same time close the position loop. The system model transformed into Laplace domain is as:

$$\frac{v(s)}{f_H(s)} = \frac{1}{\frac{c_v}{m_v s + 1}} \quad (3)$$

Where the $v(s)$ and $f_H(s)$ are the Laplace transform of speed output v and force input f_H , and the s is the Laplace variable.

VARIABLE ADMITTANCE CONTROL

To make operator easy to learn the dynamic of the lift assistant system, the more intuitive the admittance control can be the better the whole system performance will be. It is a challenging part of