Literature Review of Robot Force Control Method

Xinfeng Chen[1,a], Yichen Li[1,b] and Yuying Xiao[2,c]
[1]Wenzhou Polytechnic, Wenzhou 325000, China;
[2]Wenzhou Business College, Wenzhou 325000, China.
[a]cxf9203@126.com, [b]lyc2874853393@163.com, [c]xyy9409@126.com

Abstract

This paper introduces the robot force control methonds, 'through the arm' and 'around the arm'. In the manufacturing industry, there are many operations that require a specific amount of force to be applied. A literature review of robot force control systems is presented. This paper aims to compare two methods 'through the arm' and 'around the arm'.

Keywords

Industry Robot; Robot Force Control; Hybrid Force Control.

1. Introduction

In many cases where robot manipulators are used in the industry, they are controlled by using a position control approach. For instance, if a robot is used for pick and place the robot will be commanded to follow a predetermined trajectory which has been programmed into the robot beforehand. On the contrary, there are many industrial operations that demand that the robot manipulator can interact with the environment. Operations such as deburring, polishing, grinding etc. do not only require the robot to be aware of its position but also the amount of force that needs to be applied to perform the operation. One method to achieve this is by using the feedback values of the manipulator's position, velocity and force to calculate the desired trajectory [1].

Robot force control started to be used with remote manipulators and artificial arm control around 1950 and 1960. However, during the early stages, there were issues with stability which caused problems with controlling the robot's trajectory. It was first until the late 1960s when the first computers were used to solve force control tasks. With the rise in computational power, it became easier to test different force control methods. During this time period, the control details had to be formulated by people and there were still issues with stability for all the implemented methods[2]. After the introduction of faster computation, more flexible sensors and more sophisticated control algorithms such as joint force sensory feedback control[3] mitigate the problem to be less severe.

With the ongoing globalisation, there has become a drive towards mass customization, i.e. producing a large variety of products and with a large volume. This has caused the robot manufacturers to find new methods to automate an operation. Traditionally the desired force control is an indirect result of the robot's positioning. However, this requires that the geometry & the location of the workpiece and the end effectors geometry etc. is known[4]. If one or more of these factors are changed the operation will not be performed as desired. As a result, there have been many research papers proposed regarding robotic force control.

2. Literature Review

Industrial robots are traditionally designed to obey the desired trajectories. However, in a real manufacturing operation, physical contacts between robot and environment occur frequently which leads to inaccuracy in force control using only position control[3] because the environment is unknown to the robot. Gierlak and Szuster[5] have provided a solution for the robot manipulator to make an accurate reaction once it can interact with the environment. They state that the issue between the manipulator and the environment is due to the limitations on the manipulator's motion, such as the constraints and the model of the manipulator-environment system and control. It is, therefore, crucial to design a force controller and determine the force control parameters. There are several environment-manipulator system models which will be presented in the literature review.

2.1 Measure external force without force sensor

Surapong and Mitsantisuk[6] claim that force sensor is costly and limited to measure only external force around the area. In order to achieve high-performance force control, a disturbance observer is designed to control the position and force. This is implemented by replacing the force sensor with an observer that is used to estimate the external force. They also introduced a SCARA robot to draw the parabola that can make the end-effector follow a predetermined trajectory. Moreover, Prajumkhaiy and Mitsantisuk[7] used a SCARA robot equipped with disturbance observer to enhance the stability and performance which can measure the compensation of friction force. The non-smooth nonlinear characteristics such as friction, dead-zone and backlash are inevitable. So, the friction force might interrupt or bring negative impacts, such as overheating, reduction of speed, performance and stability issues to the force control system. Therefore, disturbance observer technique is implemented to observe the external force and the Reaction Force Observer is used to calculate the friction force. The control signal can thereafter compensate the system to reduce the friction force and improve the performance.

2.2 Integrating a force sensor to meet the pre-planned requirements

2.2.1 Measure external force with active compliance

In active compliance force control, a closed control loop will regulate the contact force between the end-effector and the robot's work environment. This means that a force sensor will be equipped with robots. According to hardware this technique is categorized into two techniques. The initial technique is 'through the arm force control' approach, where all robotic joints and links need to move to achieve the target position. This technique is presented in Fig 1. Another technique is the 'around the arm' method where only the end-effector has the force control capability instead of the whole robot having a force control function. Fig 2 illustrates how robot force control functions with a spring in the end effector. The robot performs position control and the end-effector makes a reaction from contact with curve surface[8].

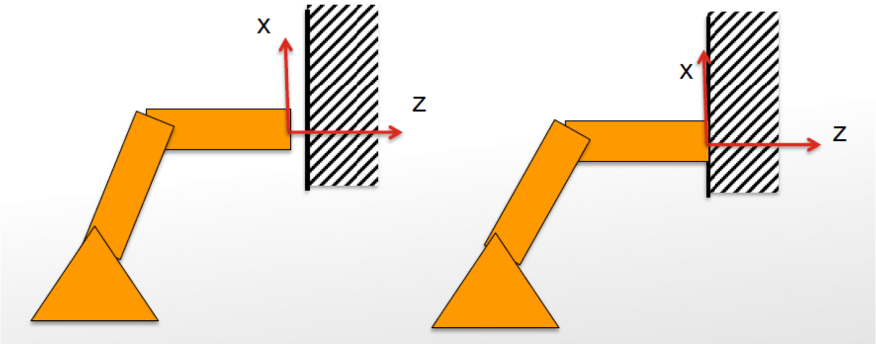

Fig. 1 'Through the arm force control' approach

The advantage of 'through the arm' technique is that it allows the robot to manipulate in a large space. However, due to the high inertia of robot, the motion of the robot arm will response slowly and limit the bandwidth of the system. Another drawback is that the robot is unable to control the force precisely as a result of its heavy weight. For this reason, a 'through the arm' technique is not suitable if the workpiece is fragile.

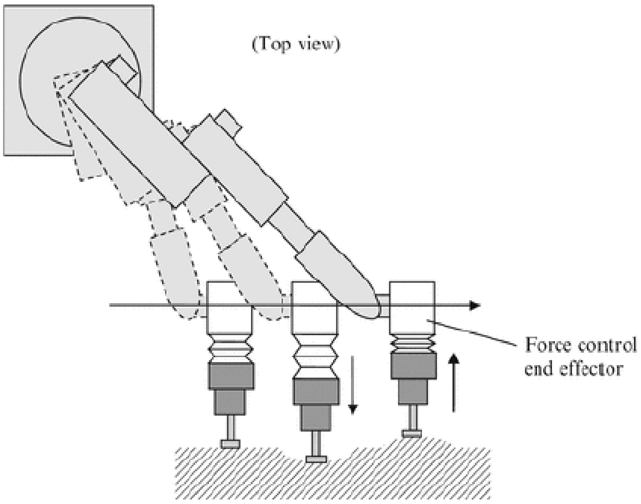

Fig. 2 ‘Around the arm’ approach[8]

In terms of ‘around the arm’ approach, the robot is manipulated in a smaller workspace due to that the end-effector must get close to the surface. Whereas, a light weight end-effector can move faster and only a small force is needed to control the robot[8].

Mohammad et al.[8] designed a six-axis macro-mini robot where macro parts are used to locate the mini robot. A new structure of the end-effector is proclaimed where the mini robot controls the force. This is presented in Fig 3. It is clear that the force sensor will detect the force between the end effector & the workpiece and only the end-effector will make a reaction.

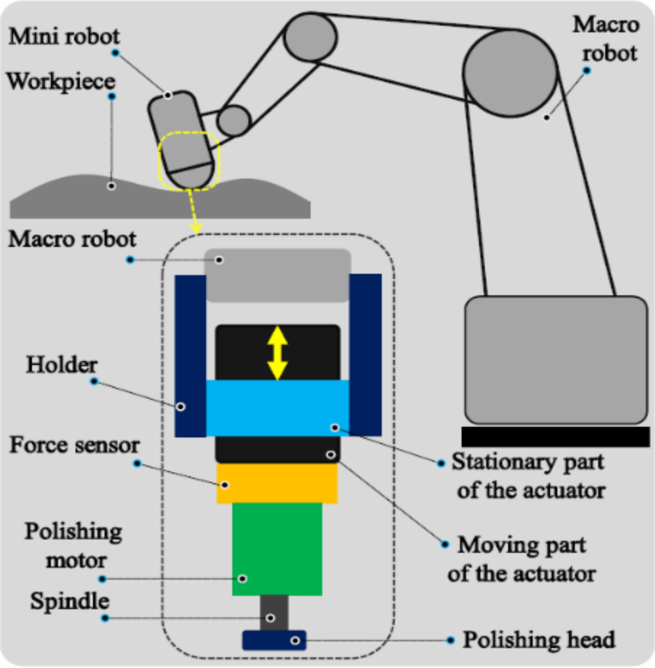

Fig. 3 Conventional structure of macro-mini robot system[8]

2.2.2 Measure external force with active compliance

In passive compliance control, by using a passive mechanical element such as springs, the contact force between the workpiece and the polishing tool is converted to a natural obedience deformation[8].

2.3 Contact Model

Several studies have analysed the contact model parameters. Stolt et al.[3] state there are 4 methods to estimate the environmental contact model. One of the methods was originally profiled by love and book. It describes how to choose the precise parameters in an impedance controller. Moreover, Roy and Whitcomb[9] presented an adaptive force controller which is based on assumption of contact stiffness. Mallapragada[10] state that the combination of contact stiffness and damping is applied in an artificial neural network. In 2006, Weber et al. proposed a contact model with multiple contact points[11].

Stolt et al.[3] claimed an environmental contact model which consists of a spring and a damper, as shown in Fig 4. Meanwhile, they derived an equation for the reaction force. The reaction force is given by

$$F = K_{env}(x_{env} - x) - D_{env}\dot{x} \quad (1)$$

where K_{env} is environmental stiffness, D_{env} stands for the damping, x_{env} is the location without loaded environment. Moreover, Yin et al.[12] used a similar structure with a force sensing system simplified as a mass-spring oscillation system with small damping. Taha et al.[13] applied this model into a drill force control robot.

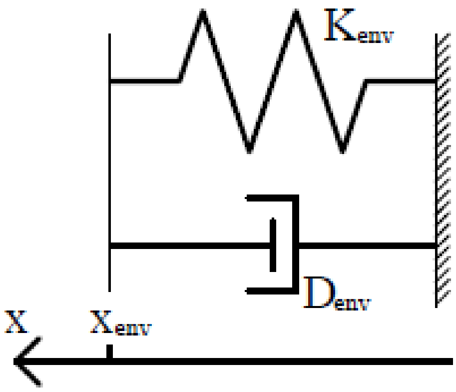

Fig. 4 Contact model[3]

2.4 Through the arm force control' approach

2.4.1 Scheme of position/force control

There are two concepts of position and force control. First, Fig. 5 demonstrates the hybrid position/force control which was introduced by Raibert and Craig in 1981[14] with natural and artificial constrains defined[15]. Winkler managed to use this model successfully by designing a robot to screw a nut using force control.

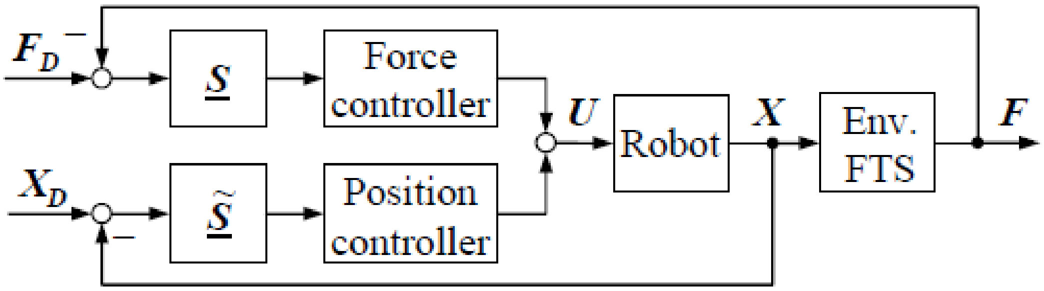

Fig. 5 Hybrid position/force control[14]

Another concept is called Parallel Position/Force Control. This concept consists of a force control action and a motion control action where the force control part is designed to compensate the motion control, illustrated in Fig. 6. As a result, the target force follows the reference force[16].

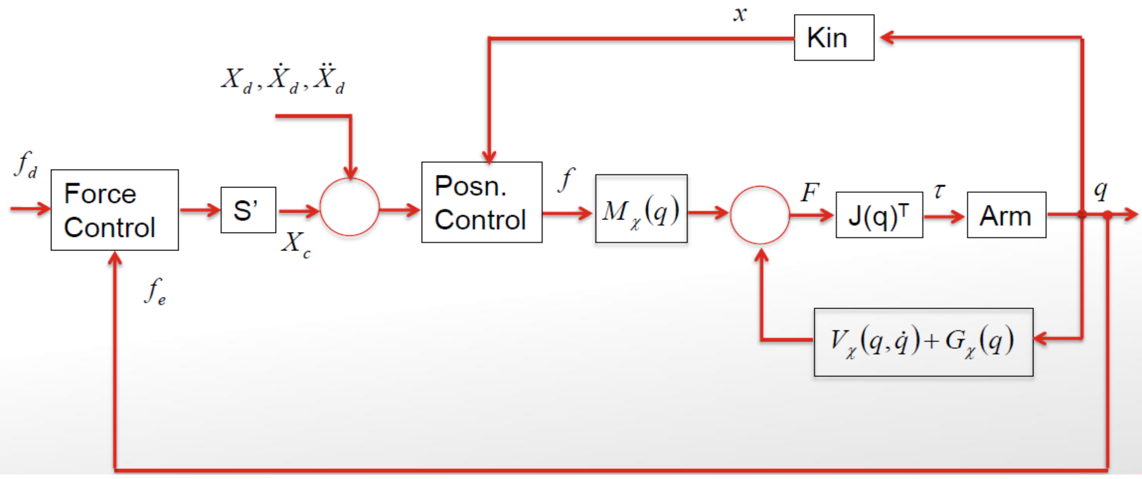

Fig. 6 Parallel Position / Force Control[16]

3. Summary

In terms of robot force control, non-force sensor equipped method is implemented to replace force sensor to perceive environment. On the contrary, integrating force sensor to meet the pre-planned requirements are also popular in common feedback control. A) 'through the arm force control' approach, where all robotic joints and links need to move to achieve the target position. B) 'around the arm' method where only the end-effector has the force control capability instead of the whole robot having a force control function.

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