Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/126/2025.20105

Research on Force Feedback Technology for Industrial Robot

Zinan Wang[1,a,*]

[1]*College of Artificial Intelligence, Nankai University, Tianjin, China*
a. 2111428@nankai.edu.cn
**corresponding author*

Abstract: Force feedback technology plays a crucial role in the field of robot control, especially in scenarios involving precise task execution. With the increasing application of robots in industrial production and automation, traditional control methods based on preset paths can no longer meet the requirements of complex and changing working environments. The force feedback system senses the force information of the robot during operation, adjusts the robot's actions and force in real time, ensures that appropriate force can be maintained during operation, and prevents damage to the working object or reduced task accuracy. While this technology primarily enhances robotic flexibility in complex operations, it has also become instrumental in advancing human-robot collaboration. By combining human perception and regulation abilities, robots are able to perform more challenging tasks. In recent years, force feedback systems that combine multi-sensor fusion, visual control, and remote operation technologies have gradually become one of the core solutions for solving force control problems in robot task execution, providing strong guarantees for safety, accuracy, and efficiency in automated production.

Keywords: Force feedback, Robot control, Multi-sensor fusion, Human-robot collaboration.

1. Introduction

With the development of industrial robot technology, its application scope is becoming increasingly wide, such as automobile manufacturing, food processing, chemical production, and medical related fields. The addition of industrial robots can effectively improve production efficiency, reduce costs, and enhance product quality, which is very important for the development and progress of the manufacturing industry [1]. Despite recent advances in robotics, traditional robot control systems still mostly rely on pre-set path planning and precise motion control to perform tasks. When dealing with changes in the environment and complex tasks, the work effect is often difficult to guarantee [2].

In order to enable industrial robots to adapt more flexibly to automated production and meet the needs of diverse work scenarios, many scholars have made attempts. In recent years, some scholars have proposed a robot system that combines force feedback technology with other sensors and control strategies, providing a solution to this problem [3]. The addition of force feedback technology has significantly improved the accuracy, reliability, and flexibility of robot operations. It brought many new possibilities for the form and scope of robot applications. This article will introduce relevant research and discuss the job characteristics of robots performing tasks under different strategies.

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/126/2025.20105

2. Force feedback technology for industrial robot

2.1. Force feedback and robot control

When robots perform tasks, they often need to move along specific paths. In addition, robots need to be able to adjust according to actual situations to ensure that they can continue to work continuously even when there are small changes in the working environment. Moreover, the real-time adjustment mechanism can also meet the needs of more precise control and ensure that workpieces and other objects are not damaged.

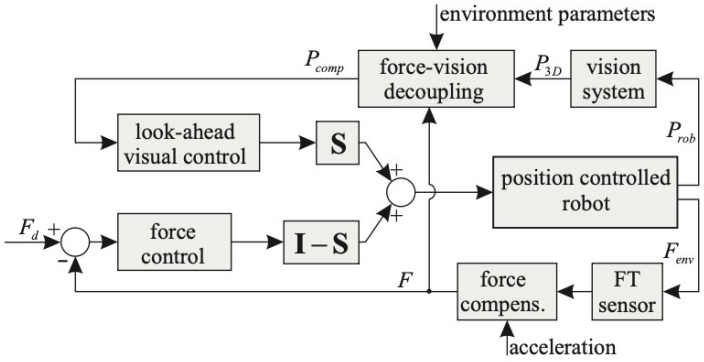

Figure 1: Hybrid control scheme with decoupling of force and vision. Matrix S selects the axes to be controlled [4]

Heiko Koch et al propose a multi-sensor fusion system that combines vision, force feedback, and acceleration sensors, the control scheme of the system is shown in Figure 1 [4]. The system utilizes visual sensors to guide the tool along the workpiece contour, while force feedback control maintains appropriate contact force. Additionally, acceleration sensors are employed to compensate for inertia-induced force measurement errors. Real time identification of environmental parameters using recursive least squares algorithm to dynamically adjust the control system to adapt to changes in the working environment. By using the "preview control" algorithm to identify the future contour features of the workpiece in advance, path prediction can be performed to avoid accuracy degradation caused by tool contact points obstructing the visual sensor.

Comparing the compensation effects of built-in sensors and external tool acceleration sensors, the results indicate that superior compensation is achieved when the acceleration sensor is directly installed on the tool for measurement. The use of acceleration sensors significantly improves the responsiveness of the force control system and reduces measurement errors caused by inertia. In addition, using corner detection algorithm can effectively reduce robot path tracking errors. With corner detection enabled, the robot can navigate path corners more effectively by stopping, rotating, and restarting. This capability allows the system to handle sharp path changes and achieve higher accuracy on complex contours.

DOI: 10.54254/2755-2721/126/2025.20105

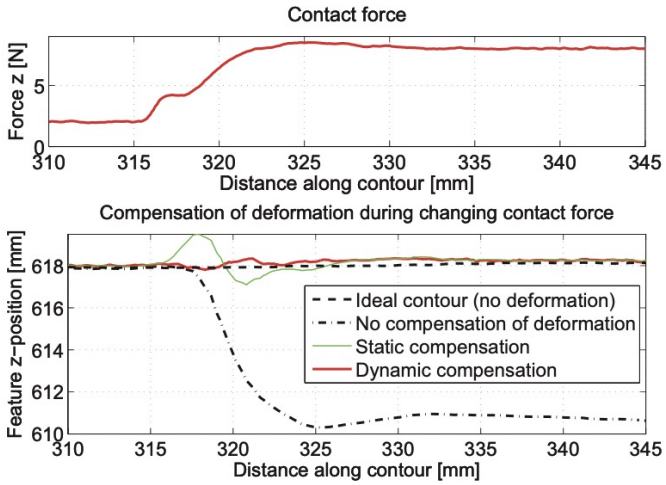

Figure 2: Visual measurement recognizes the deformation of the workpiece caused by changing contact force. Compensation reconstructs the nondeformed path for visual control [4]

Figure 2 shows the visual control error of the system when the contact force changes. Contact force may cause deformation of the workpiece, and without compensation, the system may mistakenly believe that the deformation is the true shape of the workpiece, resulting in tool misalignment. After introducing a compensation mechanism based on force sensors, the system can identify and eliminate errors caused by contact forces, allowing the tool to move along the true path of the workpiece and reducing alignment errors.

In some tasks, robots need to switch working modes in a timely manner to meet the needs of different action execution. In order to enable the robot to recognize task stages in a timely manner and make adjustments, László Rónai and Tamás Szabó use the theory of large displacement and small deformation to model the working process, and the corotational approach method of flexible structures to analyze in detail the action state of the robot during the working process [5]. On the basis of modeling, numerical simulation was used to analyze the changes in force and displacement during the working process. According to Salvador's theorem, which relates to the stability of dynamical systems, the stability of key equilibrium points was explored to determine the optimal timing for force feedback system intervention. Then, the Newton Raphson iteration method is used to solve for the displacement increment and force variation of the system, verifying its stability.

In actual experimental verification, load sensors are used to measure the force applied during the assembly process in real time, and the force displacement curve during the robot's working process is recorded. The result suggests that in the absence of force feedback control, the robot may exert excessive force during operation, potentially risking damage to the workpiece. After introducing force feedback, when the change in judgment reaches the critical point, the robot can automatically terminate the work process, ensuring the safety and stability of the operation.

2.2. Remote control of human robot collaboration

By establishing a force feedback system and optimizing the automatic control strategy, robots can independently and reliably perform specific tasks. However, the adaptability of robots is far from reaching the level of humans. Some scholars hope to combine the advantages of both by incorporating human regulation into the task execution process of robots. For tasks that require both operational accuracy and human adaptability, remote operation of industrial robots can be used to solve them.

DOI: 10.54254/2755-2721/126/2025.20105

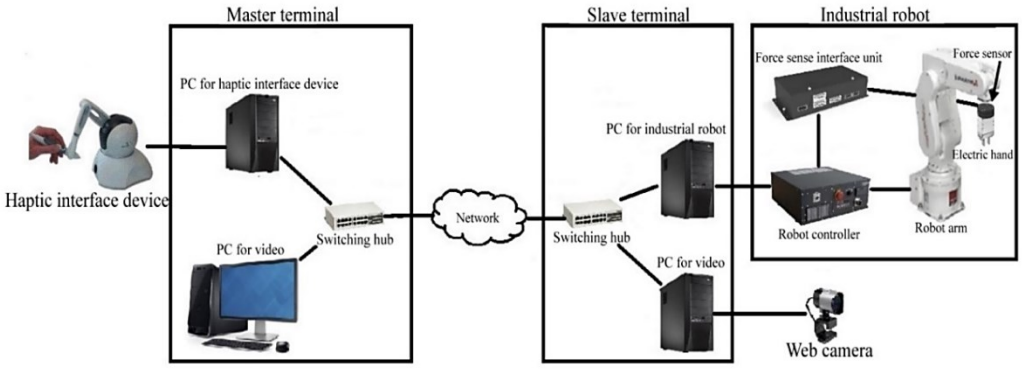

Figure 3: Configuration of remote robot system with force feedback [6]

Yuichi Toyoda et al. configured a remote robot system with force feedback, as shown in Figure 3. This system offers users dual control capabilities: a tactile interface for robot manipulation and video feedback for real-time observation of robot status. Each robot system is equipped with force sensors that can sense the force applied to objects in real time, thereby enhancing the robot's operational performance in complex tasks.

The system uses a force feedback control mechanism to automatically adjust the robot's actions and force based on real-time feedback data obtained from force sensors, thereby avoiding the application of excessive or insufficient force [6]. The study compared the efficiency differences in task execution between robot collaboration and user robot collaboration. The result data suggests a marginal increase in average operation time for robot-robot collaboration compared to user-robot collaboration. This slight time difference may be attributed to the relatively rigid force control in simple robotic tasks, whereas the incorporation of user operations introduces greater flexibility in adapting to task variations. In addition, in robot-robot collaboration, the applied force should be significantly greater than in user robot collaboration. This indicates that human users can better adjust the force applied to objects during the handling process, while robots lack flexibility in force control.

Incorporating virtual reality technology can enhance the user experience of operating robot systems and better leverage the advantages of user-robot collaboration. Claudia González et al. used the Unity 3D engine to create models of robots and manipulated objects, establishing a virtual working environment. Users interact with virtual robots through VR devices [7]. The Phantom Omni haptic device generates feedback, allowing users to perceive virtual objects and receive tactile sensations. In terms of control strategy, a three-level control structure is adopted to ensure the precise movement of the robot tool, and the attitude, approach speed, and remote position control information of the robot end are judged step by step, ensuring safety and operational accuracy. Three 3D cameras (Kinect sensors) capture the working object's position. The Iterative Closest Point (ICP) algorithm, a method for aligning 3D models, is then employed to match this data with the virtual world model. The force sensor and vision system are used for real-time data feedback to ensure safety. The result indicate that the system can effectively reduce force errors during operation and improve the stability and accuracy of remote operations. Compared to simple manual operation, robots can maintain more stable operating force, ensuring more consistent processing results.

In remote robot systems with force feedback, multi robot collaborative handling of objects can be achieved through robot position control methods that utilize force information. Satoru Ishikawa et al. used a stability control filter to avoid instability in the system under network delays and other conditions [8]. Utilize force sensors to sense the force applied to an object in real-time, and adjust the motion trajectory of the robot arm based on the force information. Fine-tuning the robot arm's position allows for a reduction in applied force, thereby mitigating the risk of object damage.

DOI: 10.54254/2755-2721/126/2025.20105

Comparing the force distribution of workpieces under six conditions: no control, dual system control, single system control, dual system automatic control, single system automatic control, and human robot cooperation. It can be seen that both the average force and maximum force data are the highest under uncontrolled conditions, while the lowest is observed in human robot collaboration. In remote robot systems, the implementation of force information control methods proves effective in minimizing the force applied by robots to objects during collaborative handling tasks. These findings underscore an important insight: human-robot collaboration not only yields the lowest force values but also enhances the overall system performance. This collaborative approach appears to provide the robot system with increased flexibility and more nuanced control capabilities.

3. Conclusion

Through advanced control strategies such as adaptive control and reinforcement learning, combined with integrated sensor systems and actuators, robots can more accurately perceive changes in the surrounding environment and adjust their actions in real time to adapt to complex task requirements. These solutions based on force feedback technology greatly improve the flexibility of robots in industrial production. With the development of VR and remote control technology, remote operating systems combined with force feedback enable operators to interact with robots in real-time through virtual interfaces, achieving precise control of operating force in remote tasks. This integration of remote operation and force feedback has expanded robot applications by enabling precise control from safe distances, providing more efficient and intelligent solutions for complex tasks.

In the future, with the advancement of artificial intelligence and deep learning technologies, robot systems may continuously optimize force feedback control strategies through adaptive learning, thereby possessing decision-making and adjustment abilities more similar to humans, intelligently responding to dynamic environmental changes through real-time data analysis and adaptive algorithms, thus enabling smooth operation even in unknown environments. In addition, the combination of force feedback technology and VR technology will greatly expand the application scenarios of robot technology, enabling robots to perform scientific research and exploration in environments that are hazardous or unsuitable for human presence, and helping humans to operate in an immersive manner without having to bear high risks.

References

[1] *Arents, J., & Greitans, M. (2022). Smart industrial robot control trends, challenges and opportunities within manufacturing. Applied Sciences, 12(2), 937. https://doi.org/ 10.3390/app12020937*

[2] *Pan, Z., Polden, J., Larkin, N., Van Duin, S., & Norrish, J. (2012). Recent progress on programming methods for industrial robots. Robotics and Computer-Integrated Manufacturing, 28(2), 87-94. https://doi.org/ 10.1016/j.rcim.2011.08.004*

[3] *Li, Z., Li, S., & Luo, X. (2021). An overview of calibration technology of industrial robots. IEEE/CAA Journal of Automatica Sinica, 8(1), 23-36. https://doi.org/ 10.1109/JAS.2020.1003381*

[4] *Koch, H., Konig, A., Weigl-Seitz, A., Kleinmann, K., & Suchy, J. (2011). Force, acceleration and vision sensor fusion for contour following tasks with an industrial robot. In Proceedings of the IEEE International Symposium on Robotic and Sensors Environments (pp. 393-398).*

[5] *Rónai, L., & Szabó, T. (2020). Snap-fit Assembly Process with Industrial Robot Including Force Feedback. Robotica, 38(2), 317-336. https://doi.org/10.1017/S0263574719000614*

[6] *Toyoda, Y., Ishibashi, Y., Huang, P., Tateiwa, Y., & Watanabe, H. (2020). Efficiency of cooperation between remote robot systems with force feedback: comparison with cooperation between user and remote robot system. International Journal of Mechanical Engineering and Robotics Research, 9(6), 900-905. https://doi.org/10.18178/ijmerr.9.6.900-905*

[7] *González, C., Sánchez, J. E., Mateo, A., Gámiz, L., Girbés-Juan, V., & Torres, J. (2021). Advanced teleoperation and control system for industrial robots based on augmented virtuality and haptic feedback. Journal of Manufacturing Systems, 59, 283-298. https://doi.org/10.1016/j.jmsy.2021.02.013*

DOI: 10.54254/2755-2721/126/2025.20105

[8] Ishikawa, S., Ishibashi, Y., Huang, P., & Tateiwa, Y. (2021). Robot position control using force information for cooperative work in remote robot systems with force feedback. International Journal of Communications, Network and System Sciences, 14(1), 1-13. https://doi.org/10.4236/ijcns.2021.141001