DESIGN OF THE MANIPULATOR SYSTEM FOR AUTOMATIC DETECTION LINE OF MECHATRONIC STRAIGHT SIDE PRESS

Xinning Liu[1,2], Chengsi Li [1,2]*
[1]Henan Polytechnic Institute, Nanyang 473009, China;
[2]Henan Material Forming Equipment Intelligent Technology Engineering Research Center, Nanyang 473009, China
**Corresponding author: Xinning Liu*
Email: liuxinninghpy@163.com

Abstract - The current work aims to solve the various phenomena in the current mechanical production. For example, the manufacturing plants require many high-quality employees, the phenomenon that frequent problems in mechanical production and errors in the production process occur due to the contradiction between high-quality requirements and the uneven quality of employees, and the production efficiency of traditional human mechanization failing to meet the social trend of intelligent production. There is an urgent need for an intelligent mechanical device that enables ordinary employees to operate according to the process. Therefore, the current types of intelligent equipment are analyzed in mechanical intelligent production, and intelligent manipulators are used for the research. With the support of the technology of the mechatronic straight side pressure, a manipulator system is established, and the system is set to two modes of operation: automatic control and semi-manual control, and simultaneously, it also avoids the occurrence of errors when the manipulator working unattended for long periods of time. After elaborating the relevant technical requirements and support, the established system of the manipulator is simulated and analyzed. By analyzing the kinematic performance of the manipulator, it is verified whether it can finish the complete blanking work. The result shows that the kinematic performance is good, and it can complete a set of blanking processes through mechanical operation, which can adapt to the current requirements of automatic mechanical production. And the success rate of multiple loading and unloading is also high using four kinds of materials, and the moving process of loading and unloading is also very stable. Therefore, it provides effective theoretical support for automatic intelligent manufacturing.

Keywords: Intelligent manufacturing; Mechatronic Straight Side Press; Manipulator; Mechanical Production; Automatic Control.

1. Introduction

In the past few years of rapid development of the industry, the number of intelligent mechanical manufacturing equipment has increased [1]. In the stamping production of manipulators, the strategy of manually deploying materials has been gradually replaced by intelligent equipment such as a mechatronic straight side press [2]. The demand for the quality of employees in mechanical manufacturing plants continues to increase, and the manipulator can effectively reduce the manufacturer's demand for human resources, and can improve the quality of employees [3], ensuring better production quality of mechanical products.

With the trend of high-tech industrialization in the world, automated production using manipulator equipment will be an inevitable trend for every country to experience [4], and it is also the first choice for customers to choose suppliers.

Now, there are still many mechanical factories in China that use manual loading and unloading to produce. But in the production of human mechanization, as Krolczyk et al. (2019) stated, factors such as total cost, cutting force, energy consumption, temperature, impact on human health, atmospheric air, and chip removal in the processing area need to be considered, it is very complicated and difficult in terms of human production [5]. Therefore, intelligent mechanical equipment is needed for production and manufacturing. Cao et al. (2019) established a model of intelligent manipulator collision detection that applies an algorithm of rapid exploration random numbers to deploy intelligent production in agriculture. The collision-free path planned by this algorithm can successfully detect collisions without collision, and can drive the manipulator from the initial position to the target position without collision [6]. Korayem and Dehkordi (2019) cooperated to develop a centralized quality fixture and a cooperative movement form with flexible links and moving joint manipulator constraints. Kinematic constraints are used to keep the distance between the arms constant by restricting the relative movement speed of the arm gripper in two stages of evaluation. Meanwhile, the dynamic models of each manipulator are weighted by using experimental test devices of single connecting rods and rotating-moving joints [7]. These results further illustrate that mechanical production using intelligent manipulators will gradually replace human production and become the general trend of development.

Therefore, it will start from the field of intelligent mechanical production to study a manipulator system with a mechatronic straight side press. Through the elaboration of relevant technical concepts, a manipulator system will be established. Through result simulation, the kinematic performance of the manipulator is analyzed to identify the usability of the manipulator. In addition, four common workpieces and raw materials are used for machining, and the manipulator is used for grab testing. Through multiple tests, the successful rate of the manipulator's loading and unloading is calculated, and whether the manipulator's movement in the process of grabbing and unloading materials is studied.

The innovation of this experiment is the application of a mechatronic straight side press as technical support.

2. Design of Intelligent Manipulator Based on Straight Side Single Point Press

2.1 Design Requirements for Intelligent Manipulators

The mechanical structure is the most basic component of mechanical equipment. How to connect the various parts of the manipulator in series through effective mechanical connections is the basic work. In the process of production, each part of the manipulator needs to bear the load of various materials in addition to its own weight [8]. From ordinary small parts to heavy metal embryos, the mechanical structure is an important bearing part. It enables each part of the manipulator to ensure very high accuracy and motion performance under the load of the external environment [9], and also needs to ensure its strength and stability. It must meet all aspects of the requirements, as shown in Figure 1.

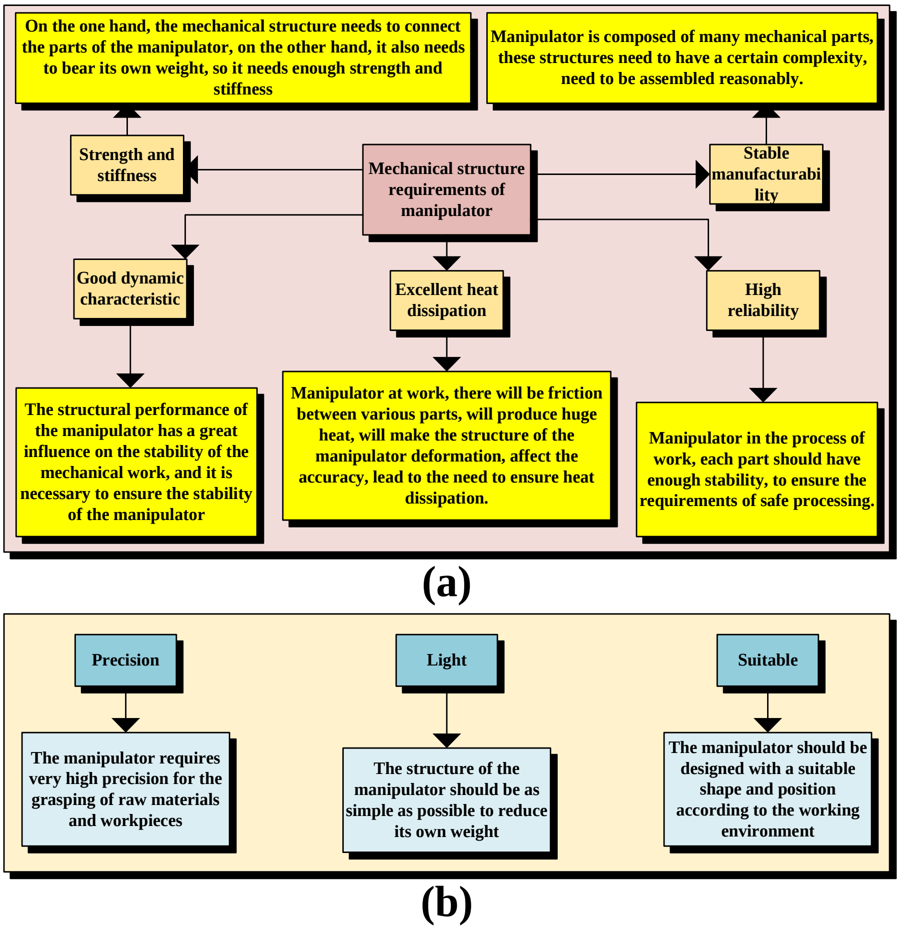


Figure 1: The requirements of the mechanical structure of manipulators ((a) the structural requirements of manipulators, (b) the design requirements of manipulators)

When designing a manipulator, it is necessary to first distinguish the movement mode of the manipulator, which can generally be divided into horizontal and vertical movement modes.

To make the whole structure of the machine simpler and easy to control, according to the current manipulator, the right-angle manipulator will be used, which is a method with many applications at present.

The accuracy of this manipulator is generally high, the design and production cost is low, which is suitable for most Small and Medium Enterprises (SMEs) to apply [10]. The structure of the manipulator is shown in Figure 2.

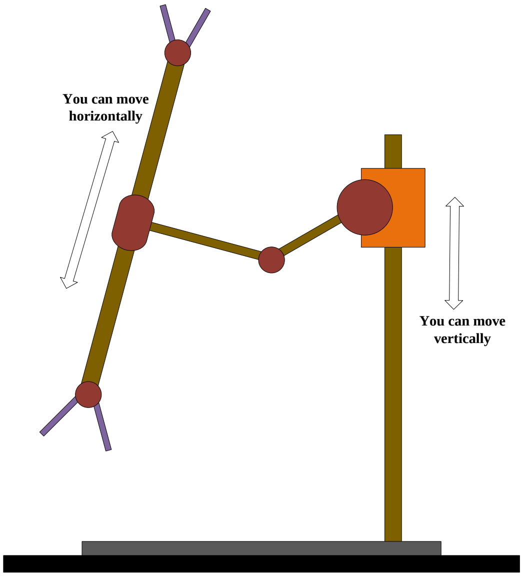


Figure 2: The brief structure of the manipulator

When the manipulator works, the body of the manipulator bears the gravity of the whole system and the inertia of motion. The skateboard and rack are the key moving parts in the horizontal movement. During the analysis process, the skateboard and the rack are assembled together for overall analysis.

They all rely on the transverse bracket to support the movement and the connecting block will make horizontally movement and vertical movement of the manipulator are connected, so when building the model of the manipulator, the model of the manipulator's body, transverse bracket, transverse skateboard and the connecting block is first established.

The process of loading and unloading of the general manipulator is shown in Figure 3.

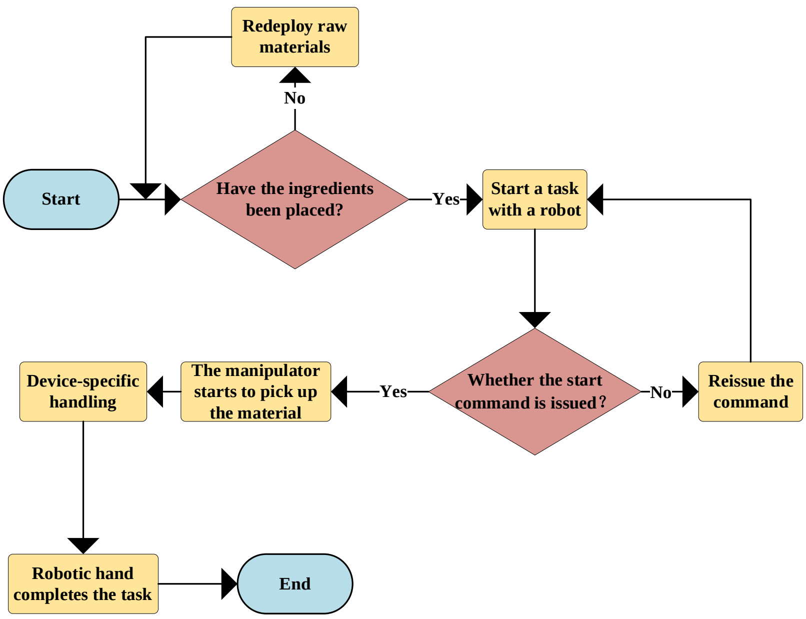


Figure 3: The process of loading and unloading of the manipulator

To meet the above requirements, the main functions required by the manipulator are the servo control function, pneumatic control function, system monitoring and fault diagnosis function, and human-computer interaction (HCI) function, among which the servo control function is to realize the movement and positioning of the manipulator. The pneumatic control function is mainly to control the balance cylinder and the vacuum suction cup to complete the handling and grasping of the workpiece. The system monitoring and fault diagnosis function mainly refer to the worker's monitoring and control of the system. When the system needs to be modified or fails, the worker can find problems through this function and deal with them in time to avoid causing greater losses. The HCI function refers to the information exchange between people and machines. The principle of the control system of the general manipulator is shown in Figure 4.

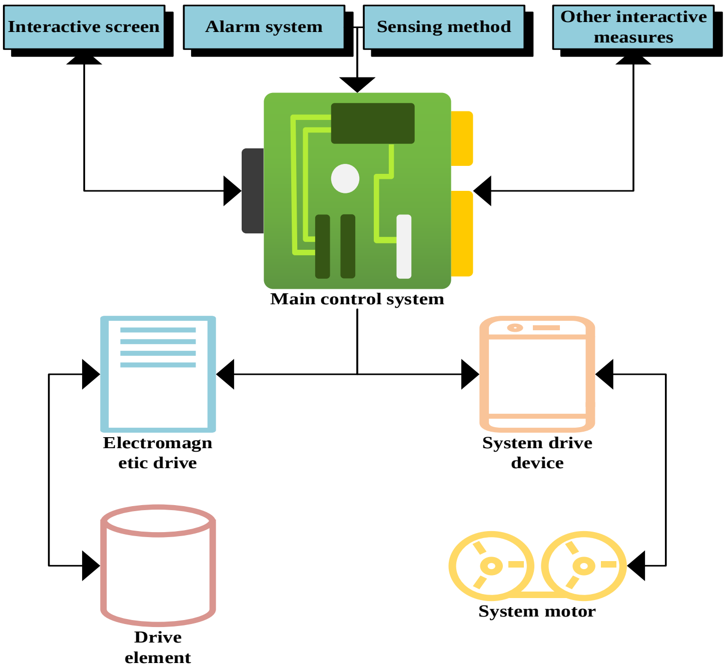


Figure 4: The principle of the control system of the manipulator

Nowadays, the commonly used devices to achieve translation include cylinder, screw drive, gear, rack and other methods. Among them, the cylinder control is unstable and is not suitable for occasions with high accuracy requirements. Screw transmission is the most accurate transmission mode among these translation modes, which is suitable for a straight-line movement in a short distance. For cases with long movement distances, the length of the screw required is very long, which makes the length-diameter ratio of the screw is very large, which will lead to the accuracy of the screw decreasing due to its own gravity. The gear and rack can move in a straight line for a long distance, and the accuracy of the current manufacturing technology continues to improve.

2.2 The Parameter Selection of Servo Motor of the Manipulator

During the process of entering the upper computer from the initial position [11], the total stroke of movement is defined as L_1, the acceleration time of the manipulator's movement is defined as t_{a1}, the deceleration time is t_{d1}, the stop time is t_{s1}, and the cycle time is t_{c1}, so during the whole movement of the manipulator The maximum speed v_{max1} is shown in equation (1):

$$v_{max1} = \frac{L_1}{t_{c1} - t_{a1} - t_{s1}} \tag{1}$$

After grabbing the material from the upper press of manipulator, during the process of placing the material on the operating platform, the total stroke of movement is defined as L_2, the acceleration time is defined as t_{a2}, the deceleration time is t_{d2}, the stop time is t_{s2}, and the cycle time is t_{c2}, then this pass The maximum speed v_{max2} in the process is shown in equation (2):

$$v_{max2} = \frac{L_2}{t_{c2} - t_{a2} - t_{s2}} \quad (2)$$

Generally, v_{max1} will be greater than v_{max2}. So when calculating the type of servo motor, it needs to be calculated according to v_{max1}. The total reduction ratio i of the horizontal movement of the manipulator is related to the reduction ratio $i1$ of the reducer and the gear reduction ratio $i2$ of the manipulator. This relationship is shown in equation (3):

$$i = i_1 \times i_2 \quad (3)$$

The equation (3) indicates that after the servo motor rotates a circle, the distance Δs of the rack movement is shown in equation (4):

$$\Delta s = \pi z_1 mi \quad (4)$$

In equation (4), z1 is the total number of the large gear [12]. m is the total modulus of the gear, and i is the reduction ratio of the horizontal movement. The maximum speed n_{max} that the servo motor needs to reach is shown in equation (5):

$$n_{max} = \frac{v_{max1}}{\Delta s} \quad (5)$$

The rotational inertia J_{z1} in the servo motor is shown in equation (6):

$$J_{z1} = \frac{\pi L \rho (z_1 m)^4}{32} \quad (6)$$

In equation (6), L is the total width of gears, ρ is the density of gear materials, m is the total modulus of size, and $z1$ is still the total number of large gears. The rotational inertia J_w loaded on the motor spindle is shown in equation (7):

$$J_w = M_1 \times \left(\frac{\Delta s}{2\pi}\right)^2 \quad (7)$$

In equation (7), M_1 is the total mass of the horizontal movement of the transverse mechanism. When the reducer is ignored, the total load inertia J_L converted on the motor is shown in equation (8):

$$J_L = J_W + 2J_{z1} + J_{z2} \quad (8)$$

In equation (8), J_{z1} is the rotational inertia converted by the large gear on the motor spindle, J_{z2} is the rotational inertia converted on the motor spindle by the small gear. From all the above equations, the total torque T_1 required by the motor manipulator to move can be obtained, as shown in equation (9):

$$T_1 = \mu_1 M_1 g \times \frac{\Delta s}{2\pi} \times \frac{1}{\eta_1} \quad (9)$$

In equation (9), μ_1 is the friction coefficient of the manipulator, M_1 is the total mass of the horizontal transverse mechanism, g is the gravity coefficient, and η_1 is the mechanical efficiency of the manipulator.

After the manipulator is designed, it needs to be installed and debugged, so there are generally two ways of manual and automatic. The manual control method is mainly used to realize the separate control of each function of the manipulator in the initial installation and debugging and when a fault occurs in the use process. The automatic control method is to realize the automatic operation of the manipulator under the pre-written program and based on the controller to complete the specified action. If there is an emergency, you can press the emergency button to stop.

2.3 The Control Method of the Mechatronic Straight Side Press

When designing control systems, the first thing to solve is the choice of control methods. There are two control methods commonly used in the industry, one is the motion controller as the core, and the other is the motion controller as the core controller of the manipulator. The horizontal and up-and-down movements of the manipulator are realized through the servo motor. Moreover, to make the manipulator run more stable and reduce the burden of the servo motor, cylinders are also used. Finally, the manipulator uses a vacuum suction cup to grab the workpiece, so the motion control part has two parts: servo control and pneumatic control. Simultaneously, in order to better realize the control of the system, the control system of the manipulator also needs some auxiliary control functions, including sensors, safety monitoring, and man-machine interface. The general movement coordinates of the manipulator are shown in Figure 5.

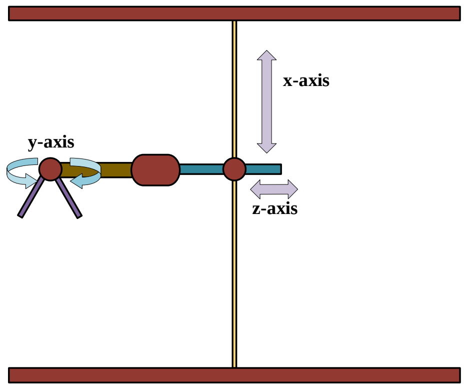


Figure 5: The movement coordinates of the manipulator

To meet the different manufacturing needs in mechanical production, the control method of the mechatronic straight side press is adopted, which is generally divided into two types: manual operation control and automatic operation control [13]. The method of manual operation control generally needs to be able to achieve single-step control of the equipment, and the automatic operation control generally needs to be able to achieve continuous control of the equipment, and can use manual strategies for debugging.

When the automatic operation control is performing the loading and unloading of the task, it is necessary to manually press the automatic button device to make it run from the origin. After running a blanking process, the next blanking process can be automatically started. If the manipulator repeatedly performs the blanking process, pressing the stop button at this time can immediately stop the equipment and debug it [14].

In general, the strategy of manual operation control is only adopted when debugging the equipment. Under the command of manual operation control, each time the manipulator completes a blanking process, it will not continue the next blanking process.

At this time, the button needs to be manually pressed to send instructions for the next blanking to the manipulator. so that the second blanking can be carried out. In general, this manual operation control is not easy to make errors compared with automatic operation control, but it requires manual and frequent send instructions [15].

The automatic operation control of the blanking process and the manual operation control of the blanking process are shown in Figure 6.

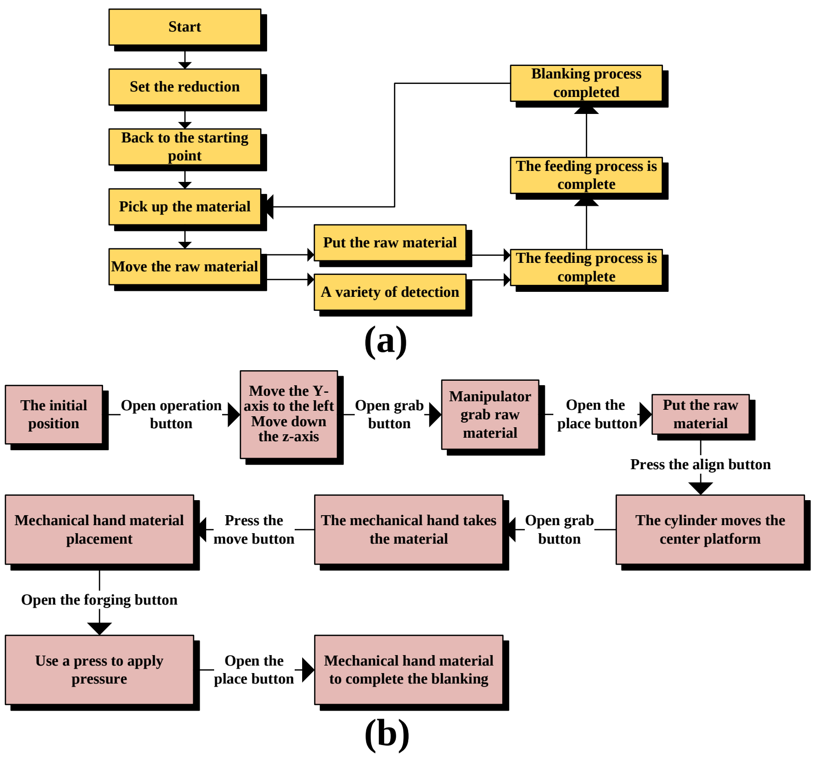


Figure 6: The automatic operation control of the blanking process and the manual operation control of the blanking process: ((a) The process of the automatic operation control, (b) The process of the manual operation control)

2.4 The Process of Finite Element Simulation

The finite element simulation is a method that uses data and values to analyze the model [16]. This method is practical and is well used in the verification of the performance of many mechanical components, as well as physical and chemical performance verification of raw materials. The basic principle of the application is the analysis of values, which can divide a whole mechanism into a variety of interconnected point units.

Through these point units to analyze, which can reduce the complexity of the entire system or raw materials. However, it should be noted that when using finite element simulation analysis, the accuracy of the final data results is not high, because the result data is an approximate solution obtained according to the division of the mechanism nodes, and only the general performance of the mechanism is speculated.

However, this does not affect the position of finite element simulation in the field of mechanical analysis. Compared with traditional analytical algorithms, the advantages of finite element simulation are shown in Table 1.

Table 1: Advantages of finite element simulation

Advantages of finite element simulation	The embodiment of advantages
Strong operational control	It can be applied in various machining industries, and most mechanical models can be simplified and simulated.
Widespread use	The partitioning performance of nodes is strong and will not be interfered with by the shape of the model.
High computational efficiency	Finite element simulation calculation uses matrix form, which has high adaptability with the computer, the calculation speed is fast, and the versatility is strong.

When establishing a finite element simulation model, how to reasonably divide the nodes of the analyzed model has a great impact on the data results. Because the mechanical structure in the actual analysis is often very complex, the characteristic distribution of raw materials is uneven, and the boundary conditions and load are also complex and variable. When establishing a finite element simulation model, the structure needs to be simplified to obtain a finite element model that can reflect the characteristics of the manipulator. When simplifying the model, four principles must be followed, as shown in Table 2:

Table 2: The testing principle of the finite element model

The principle	The specific content of the principle
Ignore widgets	In the mechanical structure, the widgets that have no effect on the performance structure such as load-bearing can be appropriately ignored.
Ignore inconspicuous features	Dimensions such as holes, fillets and chamfers with less influence on model features can be properly ignored.
Simulated connection	The original connection simulation in the mechanical structure is regarded as a rigid connection, and the threaded connection and welding have little influence on the characteristics of the structure and can be appropriately ignored.
Simplify the load	The load of the structure is appropriately simplified, and the force of the supporting base, motor, accelerator and coupling of the mechanical structure connected can be regarded as an equivalent load to ensure that the position, area and force of the contact surface remain unchanged.

When the manipulator works, the body of the manipulator is loaded with the weight of the entire structural system and the inertial force generated by the movement process. The skateboard and rack are the key moving parts in the horizontal movement. During the analysis process, the skateboard and rack are assembled together for overall analysis. They all rely on the transverse bracket to support the movement, and the horizontal movement and vertical movement of the manipulator are connected by the connecting block. So when building the model of the manipulator, the model of the manipulator's body, transverse bracket, transverse skateboard and connection block are first established. In the process of finite analysis, it is very significant to divide the mechanical model into elements. An appropriate element can not only greatly simplify the difficulty of analysis, but also improve the accuracy of the finite element analysis (FEA). The structure of the moving manipulator is a solid model. The solid linear element is used to divide the unit, which can effectively express the real situation of the manipulator. There are two commonly used division methods: tetrahedron and hexahedron. These two types of units have their own advantages. For some complex structures, tetrahedral units can be used to show the structural characteristics more clearly.

3. Experimental Verification and Result Comparison

3.1 Analysis of Kinematics Simulation of the Manipulator

The performance verification of the manipulator is realized by finite element simulation. The physical performance of the manipulator can be obtained by simulating and verifying the performance of each data during the movement of the manipulator through finite element simulation, and its structure is shown in Figure 7.

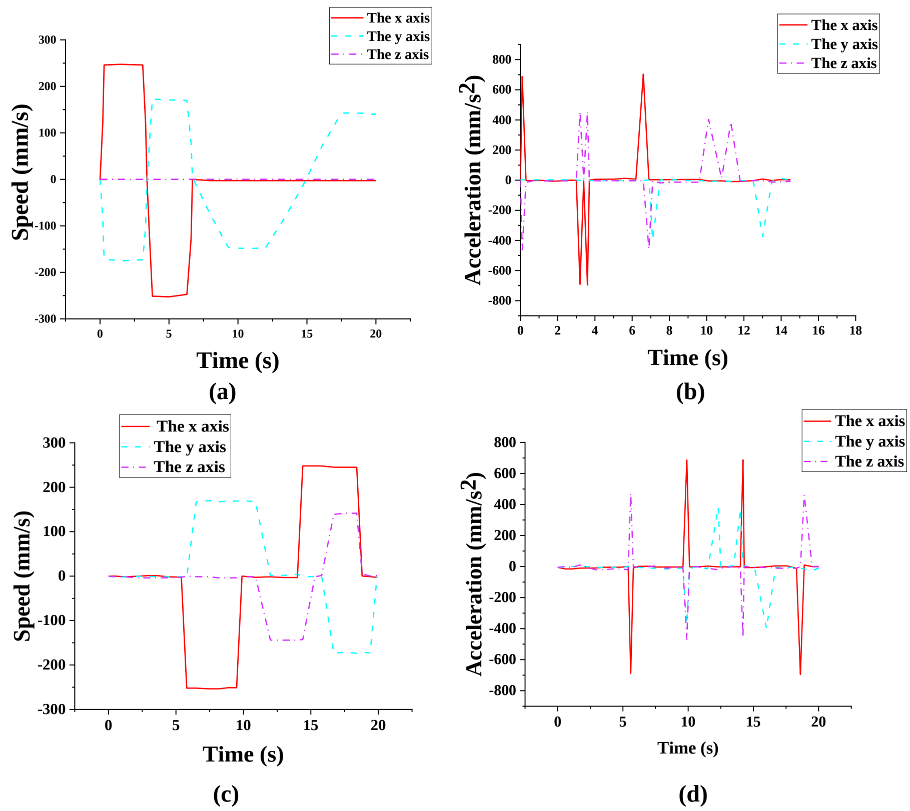


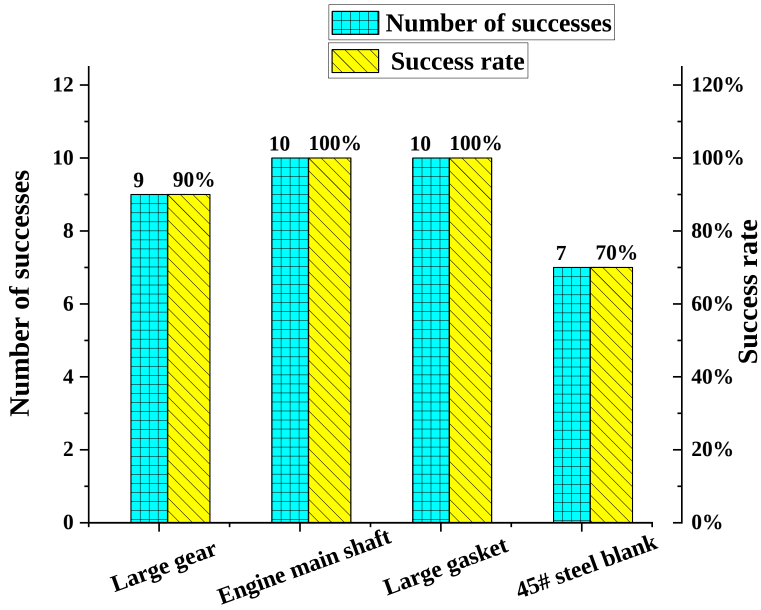
Figure 7: The results of finite element simulation of the manipulator ((a) is the loading speed curve of the manipulator, (b) is the loading acceleration curve of the manipulator, (c) is the blanking speed curve of the manipulator, (d) is the blanking acceleration curve of the manipulator)

In Figure 7, the results of the four graphs show that when the manipulator is loading and unloading, the maximum speed of the x-axis is 250mm/s, the maximum speed of the y-axis is 225mm/s, and the maximum speed of the z-axis is 150mm /s, and the changes of acceleration are relatively uniform in the three directions, and the amplitude is relatively balanced. When loading and unloading, the speed of the manipulator has a sudden change, and there are obvious acceleration and deceleration curves at the stages of beginning and end, and the rest of the operation process is relatively stable. So, it can be judged from the graph in the figure that the manipulator runs stably in the process of loading and unloading, which meets the stability requirements of machining and can work smoothly and normally.

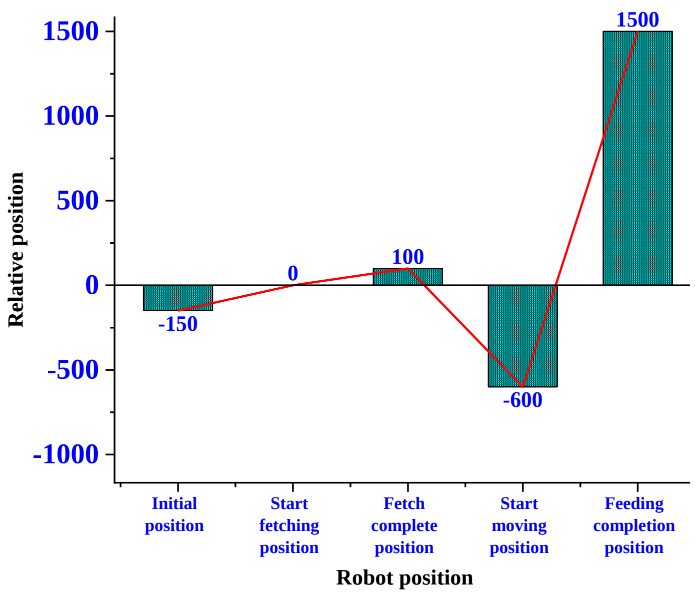
3.2 The Test of the Success Rate of Loading and Unloading of the Intelligent Manipulator

In this link, the above manipulator will be used. For the success rate of workpiece or material grasping and loading and unloading in the machining process, four kinds of materials are used to test. The first is the common large gear commonly used in machining, the second is the main shaft in the engine, the third is the large gasket in the large industry, and the fourth is the blank of No. 45 steel.

Each material is grabbed 10 times, the success rate is statistically and drawn as a statistical chart, and the moment position of the manipulator is analyzed using a simulation system. The results are shown in Figure 8.



(a)



(b)

Figure 8: Statistical analysis chart of manipulator grasping success rate and position ((a) is the grasping success rate, (b) is the position value in the process of grabbing gaskets)

Figure 8 (a) shows that when using the intelligent manipulator to grasp the workpiece and the original blank, each of the four materials has been grasped 10 times respectively, of which the number of successful grasps of the large gear is 9 times, so the success rate is 90%. The number of successful grasps of the main shaft of the engine is 10 times, and the success rate is 100%. The number of successful grasps of the large gasket is 10 times, and the success rate is 100%. The number of successful grasps of No. 45 steel blanks is 7 times, and the success rate is 70%. The reason for the high number of successes of the main shaft and gaskets is that the shape of the main shaft is special and easy to grasp, while the gasket is generally made of rubber. The purpose of the gasket is to increase the friction coefficient, so the success rate of the gasket is also high. Due to the special shape of the gear, the teeth of the gear and the manipulator are more likely to slide, resulting in the phenomenon that the gear falls from the manipulator. For the No. 45 steel blank, due to more impurities and larger quality, and irregular shape of the blank, it has less contact with the manipulator and is easy to slide, so the success rate is low.

Through the numerical analysis of the position of the manipulator's grabbing gasket in Figure 8 (b), it indicates that the position value of the manipulator is an integer. So it can be analyzed that under the condition that the manipulator can ensure sufficient grasping and does not fall, from the process of grasping the material to the moving, and finally to the complete placement of the material by the manipulator, the manipulator moves relatively smoothly without shaking. Therefore, it shows that the manipulator can bear the quality of the workpiece or raw materials well and complete the stable loading and unloading work, so the manipulator can be applied in automated production.

4. Conclusions

Nowadays, high-tech mechanical production has become the primary goal of the development of various countries, and the ultimate goal is to adopt various new technologies to achieve fully automated production.

The purpose of the research is discussed, and the structural requirements of the automatic manipulator and the manipulator in the mechanical production, and the type of the servo motor are elaborated. Combined with the mechatronic straight side press, a system of manipulator loading and unloading is proposed, which is applied to the loading and unloading work in the mechanical production process. The kinematics performance of the manipulator is verified by finite element simulation.

Through the simulated curve structure diagram, it expresses that the kinematic performance of the manipulator is good, and the stable rate change can be guaranteed in the loading and unloading process, which proves that the physical performance is good. Moreover, in the test of the success rate of the manipulator's grasping of four workpiece materials, the grasping success rate of each workpiece is relatively high. However, the phenomenon of grasping dropping is mainly caused by the irregular shape of the workpiece, not caused by the damage and instability of the manipulator.

During the whole process of grasping the workpiece material, the manipulator moves relatively smoothly, which can ensure the safety and non-damage of precision instruments and workpieces. Therefore, this kind of manipulator can be deployed and applied in mechanical production, which provides a certain reference for intelligent mechanical production. However, the loading and unloading accuracy of the manipulator has not been verified yet. In the follow-up work, the performance of this aspect will be focused on, and how to reduce the failure of grasping is also a problem that needs to be considered, such as adding a rubber layer to the manipulator. Measures can be taken to increase friction.

Acknowledgement

This work was supported by Science and Technology Development Plan of Henan Province (182102210266).

References

[1] Huang R., Li J., Wang S, et al. (2020) A robust weight-shared capsule network for intelligent machinery fault diagnosis [J]. IEEE Transactions on Industrial Informatics, 16(10), 6466-6475.

[2] Dou W., Zhong G., Cao J, et al. (2021) Soft Robotic Manipulators: Designs, Actuation, Stiffness Tuning, and Sensing [J]. Advanced Materials Technologies, 2100018.

[3] Smyrnova I., Akimov O., Krasivskyy O, et al. (2021) Analysis of the application of information and innovation experience in the training of public administration specialists [J]. International Journal of Computer Science & Network Security, 21(3), 120-126.

[4] Davidson J., Bhusal S., Mo C, et al. (2020) Robotic Manipulation for Specialty Crop Harvesting: A Review of Manipulator and End-Effector Technologies [J]. Global Journal of Agricultural and Allied Sciences, 2(1), 25-41.

[5] Krolczyk G. M., Maruda R. W., Krolczyk J. B, et al. (2019) Ecological trends in machining as a key factor in sustainable production–a review [J]. Journal of Cleaner Production, 218, 601-615.

[6] Cao X., Zou X., Jia C, et al. (2019) RRT-based path planning for an intelligent litchi-picking manipulator [J]. Computers and Electronics in Agriculture, 156, 105-118.

[7] Korayem M. H., Dehkordi S. F. (2019) Dynamic modeling of flexible cooperative mobile manipulator with revolute-prismatic joints for the purpose of moving common object with closed kinematic chain using the recursive Gibbs–Appell formulation [J]. Mechanism and Machine Theory, 137, 254-279.

[8] Qiu Z., Li C., Zhang X. (2019) Experimental study on active vibration control for a kind of two-link flexible manipulator [J]. Mechanical Systems and Signal Processing, 118, 623-644.

[9] Heishman A. D., Daub B. D., Miller R. M, et al. (2020) Countermovement jump reliability performed with and without an arm swing in NCAA Division 1 intercollegiate basketball players [J]. The Journal of Strength & Conditioning Research, 34(2), 546-558.
[10] Le C. H., Le D. T., Arey D, et al. (2020) Challenges and conceptual framework to develop heavy-load manipulators for smart factories [J]. International Journal of Mechatronics and Applied Mechanics, (8), 209-216.
[11] Zhang C. (2020) PD plus dynamic pressure feedback control for a direct drive stewart manipulator [J]. Energies, 13(5), 1125.
[12] Soe W. H., Kleinwächter M., Kammerer C, et al. (2020) Mechanics of Molecule-Gears with Six Long Teeth [J]. The Journal of Physical Chemistry C, 124(41), 22625-22630.
[13] Li X., Tan C., Liu C, et al. (2020) Atomic-scale observations of electrical and mechanical manipulation of topological polar flux closure [J]. Proceedings of the National Academy of Sciences, 117(32), 18954-18961.
[14] Su H., Hu Y., Karimi H. R, et al. (2020) Improved recurrent neural network-based manipulator control with remote center of motion constraints: Experimental results [J]. Neural Networks, 131, 291-299.
[15] Chen J. I. Z., Chang J. T. (2020) Applying a 6-axis Mechanical Arm Combine with Computer Vision to the Research of Object Recognition in Plane Inspection [J]. Journal of Artificial Intelligence, 2(02), 77-99.
[16] Morales Bieze T., Kruszewski A., Carrez B, et al. (2020) Design, implementation, and control of a deformable manipulator robot based on a compliant spine [J]. The International Journal of Robotics Research, 39(14), 1604-1619.