A People-Oriented Designing for Pattern Carving Intelligent Control Integrated Device

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Abstract: Aiming at solving the problems of weak human-computer interaction, poor scalability, low system integration, and lack of information management capabilities of the original engraving equipment, a set of pattern engraving intelligence integrated management and control device has been developed. The device flexibly integrates the main processes of engraving machining, detection, sorting, etc., and realizes the automatic machining of multi-mode engraving tasks such as on-site touch screen delivery, remote machine vision collection, network PC communication, and mobile APP sending. It can identify and evaluate the characteristic parameters of engraved final products over non-contact machine vision; and use the SCARA robot for intelligent sorting and palletizing of engraved final products. In addition, its information management platform can realize real-time monitoring of production status and production data storage and statistical analysis. In general, the device realizes the intelligent upgrade and informatization transformation of traditional engraving equipment.

1. Introduction

As a typical branch of the mechanical field, the carving machining has attracted more attention because of the growing market's demand for jewellery, signs, and handicrafts[1]. In the past, traditional engraving machining generally used manual operation mode[2]. With the continuous improvement of people's requirements for accuracy and speed, many scholars have successively proposed the use of computer control and numerical control technology to realize the transformation of engraving machinery. Emphasis is placed on the transformation and design innovation of mechanical structures, multi-axis motion control schemes, and trajectory optimization planning algorithms[3][4]. In recent years, the automation and intelligence of engraving equipment has been greatly improved[5].

Foreign engraving machines are mainly based on numerical control technology, and the products have the characteristics of high precision and good man-machine interface. For example, the CNC systems of Germany's Siemens, Japan's FANUC and other companies can achieve 28-axis servo control; the new CNC equipment HELIRONIC POWER developed by Germany's WALTER company is not only equipped with FANUC310i CNC system, but also its operating system adopts Windows system; it can realize online measurement, and its engraved products have the characteristics of high precision and high speed [6]. The main problem of these CNC machining centers is that they are expensive and the after-sales maintenance costs are also quite high [7].

Although the development of domestic CNC engraving machines started late, related technologies have been improving [8]. For example, the HELIXNC-5A five-axis CNC tool grinder prototype developed by Shanghai Haige adopts Wuhan Huazhong CNC system, which can realize 5-axis linkage; many brand machines such as "Jingdiaol" from Beijing Jingdiaol and "Woodpecker" from Shanghai...
develop rapidly and occupy a certain market share [9]. After investigating and analysing the domestic engraving equipment, it is found that there are three main shortcomings of the original engraving equipment: First, the electrical control circuit is adopted by the original engraving machining equipment to realize automatic control. The human-computer interaction capability of this equipment is not strong, and the function scalability is poor; the ability to adapt to user customization is weak. Second, the quality of the original engraved products generally depends on the detection instrument, which is completed by manual detection. This detection method requires high personnel experience, and the detection accuracy is difficult to guarantee. The original engraving and machining automation equipment cannot be connected to the network, and remote equipment monitoring cannot be performed. The operating status of the equipment is difficult to be monitored, and the data of the equipment cannot be statistically analysed and managed.

In order to improve the global competitiveness of manufacturing industry, it is necessary to develop new machine with comprehensive advantages. In this paper, based on the "people-oriented" design concept, via transforming and redesigning, a new pattern carving intelligent control integrated device has been developed. The device aims at automation, intelligence, networking, and informatization. It strengthens the platform’s human-computer interaction capabilities and enhances the convenience and visual rendering effect. The direction is to meet the individual needs of users. For the principle of improving quality, increasing efficiency and reducing costs, it greatly realizes the in-depth integration of informatization and automation, and expands the informatization management and remote monitoring capabilities.

The remainder is organized as follows. The second part gives the architecture design and the third part introduces main module design of the device; the fourth part is the debug and function; and the fifth part is the conclusion.

2. Architecture design

The integrated device of intelligent management and control of sample carving is mainly composed of three parts: on-site monitoring layer, WEB service layer, and WEB terminal application layer. On-site monitoring layer mainly performs data collection and on-site control of equipment; WEB service layer is used to store and transmit monitoring data; and WEB terminal application layer realizes monitoring functions and performs analysis and management of data.

![Figure 1 The hardware structure of the intelligent carving device](image-url)
3. Main module design

The main module of the intelligent carving device consists of three parts: engraving machining module based on X-NET bus multi-axis servo linkage, machine vision recognition module based on Canny algorithm and Hough transform, engraving product sorting module based on SCARA robot.

3.1 Design of engraving machining module

3.1.1 Module design based on X-NET Bus multi-axis servo linkage

The engraving process is mainly driven by a four-joint manipulator. Among them, the three joints constitute a three-dimensional module, which is driven by three servo motors to control the displacement of the tool in the X, Y, and Z axes during the machining process; the fourth joint is mainly used to control the tool's displacement. The action also relies on the servo motor to realize the engraving operation. Under normal circumstances, AC servo motors are usually driven by PLC output high-speed pulse+ direction control mode. But in this way, firstly, the field hardware wiring is complicated, and secondly, it is restricted by the PLC high-speed pulse output port. This article adopts multi-axis servo linkage control method based on X-NET bus to drive. In the engraving machining module's hardware configuration, the hardware circuit connection design extends a network communication module XD-NE-BD on the PLC controller and connects a communication board to the three-axis motion servo driver of the robot. In addition, it uses R485 communication standard for channel connection and realizes data exchange through X-NET protocol.

3.1.2 Module design for multi-mode task input and implementation

This article starts from meeting the needs of user customization and designs according to the principle of customization. Various types of task input functions are formed, which can achieve the specified tasks of engraving machining. The module supports the following three methods of engraving machining tasks: First, the user inputs the size and quantity of standard parts engraving machining through the touch screen. Second, AutoCAD drawings designed by users are imported to determine the shape of engraving and machining graphics. Third, the machine vision system obtains the pattern of the customized finished product by the user. The engraving process is mainly driven by a four-joint manipulator. The three-dimensional module is mainly used to control the position and trajectory of the tool, and the other joint is mainly used to set up the engraving tool to realize the engraving operation of the parts.

When the user inputs the size of the product to be engraved from the touch screen, based on the Modbus communication protocol, the PLC reads the machining information from the touch screen, then based the X-NET bus protocol, it communicates with the four-joint manipulator to drive the four servo motors to complete the machining tasks.

When the part information is imported by the user through the AUTOCAD drawing, the contour feature is obtained by connecting the graphic entity of the part outline into a Polyline multi-line segment, and its outline point information is expressed by the position and shape. Use MATLAB software to read the characteristics of the outline points of the graph, and the acquired data information is saved in the form of a .mat file. Each straight line segment and arc segment in Polyline are connected end to end in turn, which is convenient for determining the direction of movement of the tool during machining. The
specific method: the vertex coordinate value is stored in 10 sets of codes, and the vertex convexity is stored in 42 sets of codes. A convexity of 0 is the vertex of a straight line, which connects to the next vertex as a straight line. When the convexity is not 0, it is the apex of the arc, which is connected to the next apex to form an arc. A negative convexity indicates a clockwise arc, and a positive convexity indicates a counterclockwise arc. An absolute value of convexity less than 1 indicates that the arc wrap angle is less than 180°, and an absolute value of convexity greater than 1 indicates that the arc wrap angle is greater than 180°.

When the machining information according to the given task is inputting, the PLC regularly drives the four-joint manipulator to engrave the parts. And the data information generated by MATLAB in the .mat file must be transmitted to the PLC. The method is to use the OPC protocol, and the information of the .mat file is read by the PLC to obtain the machining information. When the engraving is processed by the user, the characteristic parameters of the engraving movement trajectory are obtained through the mode of visual guidance. The design process of its PLC program is: first import AUTOCAD graphics in offline state, and after processing by X-Sight software, graphics characteristic parameters can be read by PLC through MODBUS communication mode. After starting the equipment and calling the formula confirmation, based on the X-NET bus protocol, the PLC calls the motion control program to drive the 4 servo motors to complete the processing tasks.

3.2 Design of the machine vision detection module

3.2.1 Hardware structure of machine vision detection
In the detection process of this engraved product, the machine vision detection technology and the image machining technology are used to detect different types of finished products. X-sight studio software is used for programming, and the geometric characteristic parameters of the finished image are learned, processed, and transmitted. Modbus communication is used to connect the PLC and the smart camera, the PLC can obtain the detection information of the finished product. Finished product detection information and standard data information are compared and calculated by the PLC, then the test results are output, and the information is displayed on the touch screen in real time.

3.2.2 Real-time adjustment technology of light source brightness for machine vision system based on closed-loop control
In the visual detection system, the brightness of the light source determines the image quality of the product and directly affects the accuracy of the detection system. At present, the commonly used light sources are generally pre-set according to the finished product, and there is little consideration of the impact of ambient brightness of the test site. In order to overcome the shortcomings of the prior art, this paper proposes a real-time adjustment method of light source brightness based on closed-loop control. It enables the light source to actively adjust the light intensity according to the combined action of the external ambient light and the light source contrast colour card, so that the inspected product can obtain the best lighting state to ensure the quality of the image.

The method of real-time adjustment is as follows:
- Calibrate the best brightness value A of the contrast colour card image according to the tested best state of the finished product;
- Provide a constant working current for the LED light source through Modbus communication between the PLC and the light source controller, and the LED light source illuminates the inspected product and the contrast colour card;
- The CMOS image acquisition module of the smart camera acquires the images of the finished product and the contrast colour card under the LED light source. The DSP image machining and analysis module processes the collected contrast colour card image, then compares the brightness value of the contrast colour card image with the calibrated optimal brightness value A, and sends the analysis result to the PLC. PLC uses PID algorithm to change the output value according to the analysis result, and
indirectly adjusts the output current of the light source controller until the inspected product and the contrast colour card image reach the best state;

- When the light source of the external environment changes and the smart camera detects that the brightness value of the contrast colour card image is inconsistent with the optimal brightness value A, the third step is repeated. When the brightness value of the contrast colour card obtained by the CMOS acquisition module reaches the best brightness A, the closed-loop control can be realized. It can enable the finished product contour visual detection system to adjust the brightness of the light source in real time according to the change of the external light intensity, overcome the influence of the external ambient light, and ensure the quality of the image of the finished product being inspected. It enables the visual detection system to adjust the brightness of the light source according to changes in the external light intensity, overcome the influence of the external ambient light, and ensure the quality of the image of the finished product.

### 3.2.3 Application of image recognition method based on the Hough transform in quality inspection module

The accuracy of quality detection directly affects the subsequent machining of products. For this reason, image machining technology is introduced into the detection system, and applied research on image feature acquisition algorithms is carried out. This paper mainly uses the Canny algorithm to detect the edge of the finished product, and then uses Hough straight line, circle transformation, and contour coordinate transformation to identify the basic components of the finished product edge, identify and classify the processed finished product contour, and determine the side length, Key geometric features such as area and geometric centre are extracted, and compared with the standard model to provide quality detection results.

This design improves the algorithm and proposes an improved algorithm for contour coordinate transformation. The process is as follows: firstly, mark the contour coordinates \((x, y)\) of the final product’s shape; secondly, convert it to polar coordinates \((\rho, \theta)\), where \(\rho\) represents the distance from the point on the finished product’s contour to the centre of gravity; then, according to the characteristics of \(\rho\) distinguish the shape of the finished product. Next, according to the shape of the finished product, the features of the finished product are extracted: side length, area, perimeter, etc. When the three-dimensional manipulator grasps the finished product, the centre of mass of the finished product is used as the position of the sucker to suck the finished product. The formula for calculating the centre of mass of the final product is as follows:

\[
x_m = \frac{1}{N_s} \sum_{(x,y)\in S} x, \quad y_m = \frac{1}{N_s} \sum_{(x,y)\in S} y
\]

In formula (1), \(S\) represents the connected area; \(N_s\) represents the number of pixels in the connected area; \((x_m, y_m)\) is the coordinates of the centroid point.

### 3.3 Design of sorting module based on SCARA robot

The main function of the sorting control module is based on the results of the machine vision detection of the previous station, and according to the actual size of the standard and the allowable deviation of the qualified parts, to carry out the sorting operation of the qualified products and waste parts. The sorting work is mainly done by SCARA robots. The SCARA robot has four degrees of freedom, including three rotating joints and one moving up and down joints. The axes of the three revolute joints are parallel to each other, the spatial posture of the robotic arm can be determined, and the spatial position of the fixture can be determined by cooperating with the up and down moving joints.

The specific sorting process of the finished product based on the SCARA robot is as follows:

When the SCARA robot is powered on and reset, it first returns to the origin. After pressing the start button, the robot moves to the position of the finished product to pick up it. According to the judgment result on the finished product’s type and whether it is qualified, the finished product is placed in the
designated material box. Then the robot continues to return to the origin and waits for the arrival of the next instruction.

In the sorting process, the SCARA robot grabs the reference point of the final product, which mainly depends on the coordinate of the center point of the finished product read by the machine vision of the previous station to locate. Since the center of the finished product read by the camera is relative to the camera's visual coordinates, the SCARA robot action is relative to the robot system coordinates. The problem is that the coordinate value of the center of the final product does not correspond, based on the two coordinate systems. The solution is as follow: First, by calculation, the system of equations for the conversion between the space coordinates of the final product in the camera shooting and the coordinates in the robot space is obtained. Secondly, after multiple teachings and multiple sets of data are acquired. Third, these values are substituted into the equations, and three coordinate values are obtained through calculation. These values are used to control the SCARA robot, the final product center is found, and the grasping task is completed.

3.4 Management and control platform design

The industrial internet equipment layer is mainly composed of hardware devices such as sensors and robots; the control layer uses PLC as the field controller to control the equipment, and displays the equipment information, the final product detection and sorting information in real time through the touch screen; through the gateway, the information of the final product is transmitted to the cloud platform to provide services for users as an industrial Internet cloud infrastructure; the industrial Internet platform layer is used to complete equipment management, data statistics and other operations, which can realize APP design, management, equipment operation analysis and other functions; the client can realize multiple users to access and share data at the same time.

The main operations of the data uploading process include configuring communication protocols, setting up cloud services, and synchronizing alarms and monitoring points. The configuration of the platform includes the configuration of engineering, equipment model, gateway and equipment, and collected parameters. The following information can be remotely monitored on the cloud platform: One is the position information and operating speed of the four-axis robot used for processing, the second is the result information of visual inspection of the final product, the third is the 3-axis coordinate position and speed of the SCARA robot used for the sorting operation, and the sorting result of the engraved product. Data such as failure rate and alarm information of engraving equipment support statistical analysis.

4. Run and debug

4.1. The PLC program design flow of the device’s main controller
When the power is on, the four-axis manipulator returns to the original position. After inputting the machining information parameters from the touch screen and pressing the start button, the machining procedure starts to run. When the machining procedure is over, the PLC controls the servo motor to make the conveyor belt move and transport finished product to the detection station. After the photoelectric switch senses the finished product, it sends a signal to the PLC, and the PLC controls the servo motor to stop working and makes the conveyor belt stop. The smart camera takes pictures to obtain the finished product information and performs calculations in the script, and then sends the processed image information to the PLC. After the PLC receives the workpiece information, it judges according to the type of the product, and controls the servo motor to work so that conveyor belt travels to the corresponding position. The SCARA robot communicates with the PLC, grabs and places according to the obtained coordinates of finished product, so as to realize the detection and sorting function. All actions are synchronized with the cloud platform. During the debugging process, other two methods can be used to input the machining information to complete the engraving task. The debugging process is shown in Figure 2.
4.2 Function of the device

The detailed function are as follows:

The device integrates the main processes of modern engraving equipment: automatic engraving machining, finished product quality detection, and material sorting. And it supports two working modes: manual and automatic.

- In the manual mode, the user is allowed to freely select the required process.
  
  If the manual machining is required, first the users select the finished product category, and then input relevant machining parameters on touch screen and start the button to realize product engraving machining.

  If the manual detection is required, first the users judge whether there is a finished product to be inspected at the station. If it is yes, the users press the start button to enable machine vision detection, then the detection result will be returned and displayed on the touch screen.

  If the manual sorting is required, first the users check whether there is a sorted finished product at the station, then press the start button according to the pass or fail test result given by the touch screen. The SCARA robot completes the sorting operation and sorts the finished products into the corresponding boxes.

- In the automatic mode, all processes of task release, machining, quality detection, and sorting are linked. When the users select the type of the finished product to be processed and enter the machining process parameters, the equipment automatically completes the machining, detection, and sorting operations of the specified planned number of finished products. The operation status, detection and sorting results of all engraving machining equipment can be monitored in real time through the touch screen, PC, and the mobile phone.

  All the data such as the failure rate and quality detection results support statistical analysis.
5. Conclusions

The device comprehensively applies computer technology, communication technology, machine vision detection technology and automatic control technology. It not only realizes automatic control of pattern engraving equipment, but also shows network control of remote equipment based on the Internet. While realizing the on-site human-computer interaction function of the main processes, it can also provide the data management of the engraving process and feedback the production quality of the product in real time. The information-based intelligent control platform and big data system can not only serve on-site production management, but also provide decision-making basis for the improvement of production process and production efficiency. Further pushing this product to industrialized application will surely produce very good industry value and economic benefits. Its features are as follows:

5.1 Aiming at "people-oriented", the engraving production line has been comprehensively and systematically innovated

From the perspective of operating users, the human-computer interaction capability of engraving machining has been fully improved. In the engraving machining, detection and sorting process, the touch screen is used to support the user to monitor the real-time status of the device and input the standard parameters of the machining and detection. It is also used to support users to perform manual teaching of on-site sorting points, and to support real-time display of sorting status animations to improve operation convenience and flexibility.

Aiming at the needs of consumer users, the engraving machining mode has been customized for users, and the device has realized the functions of process customization and diversified tasks. In the engraving process, there are often standard geometric figures and some non-standard figures to be processed. In the design process, two aspects are considered: one is that the material of the processed blank is different, and the process parameters used in its engraving are different. In the design, the single-function application mode was changed, and the recipe was used to store and call the machining parameters. The second is that the graphics are processed diversified. When the regular finished product is processed, the user uses the interactive interface to input the coordinates of the graphic machining point to complete the machining task; when the irregular parts are processed, the user uses the visual guidance method to read and store the graphic characteristic parameters through the window of the machine teaching.

For equipment purchasers, the engraving production line has been innovated in a flexible combination. The device is equipped with an independent controller for each engraving process, supports stand-alone operation, and is equipped with an independent T-Box, which is convenient for users to perform remote APP control. The bus module is used, and the bus control technology is used for hardware connection, which is convenient for users to carry out the free combination of multiple processes.

For users of engraving production management, the goal is to improve quality, increase efficiency and strengthen management. Advanced machine vision technology has been adopted, so that the engraved finished product can be measured without contact. Industrial robot technology is used in the sorting, palletizing, and packaging of engraved finished products. The application of this technology saves labour, improves work efficiency, and reduces equipment operating costs. In terms of equipment monitoring and management, based on the remote PC and cloud platform, a monitoring and management platform has been developed, which is used in the engraving production process. It realizes real-time remote monitoring of engraving equipment. This will not only bring convenience to equipment maintenance, it will also effectively promote the efficient management of engraving equipment, as well as improve the process, and further improve the quality of production. It fills the gap of the deep integration of informatization and intelligent control in the field of engraving machining.

5.2 In terms of quality inspection of final products, the adaptability and reliability of the device are improved.

In the quality detection of engraving products, the machine vision detection environment brightness adaptive function is realized. Based on the Canny algorithm and contour coordinate transformation, the
recognition of the characteristic parameters and contours of the finished product is realized, which improves the adaptability and reliability of the device.

When the quality of engraved products is inspected, due to the different changes in the surrounding environment, the device is mainly for general application scenarios. For situations where natural light changes are difficult to predict, a closed-loop control method is adopted to detect the brightness of the environment automatically. Adaptation adjustment is realized, which ensures that the detection environment is not affected by the ambient light of the industrial site and ensures the stability of the measurement. In the state of constant light source brightness, for the contours drawn by different engraving processes, the smart camera is used for image acquisition, and the image is first preprocessed, and then based on the Canny algorithm and the contour coordinate transformation method, the image feature parameters are recognized, this machining method improves the accuracy of the measurement.

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