Journal of Electronic Research and Application, 2023, Volume 7, Issue 6
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Fully Automated Paper Document Sorting Robot Design

Guo-Long Yang*, Biao-Hua Zhang

Zhanjiang Preschool Education College, Zhanjiang 524000, Guangdong Province, China

****Corresponding author:*** Guo-Long Yang, ygl1367145@sina.com

Abstract: A fully automated paper document sorting robot was developed in this project. This robot classifies documents efficiently and accurately. The objective of this project was to improve the efficiency of classifying or sorting paper documents, reduce costs, and save time. The robot can classify documents according to user-defined rules, such as keywords, dates, serial numbers, bar codes, and the meaning of paragraphs. Since it can classify or sort documents intelligently, it can complete large-scale document classification quickly. The robot is constructed using an aluminum profile to create a box-type truss gantry structure frame. It was built on the LubanCat 4 motherboard and controlled through Python language programming. Driven by a stepper motor to move the manipulator. The camera module is combined with an artificial intelligence algorithm to recognize paper in real time, and the text is recognized after taking pictures of the paper. The sorting function is performed by several sensors. In addition, a web-based human-computer interaction platform was developed using the Flask web framework in Python. Users could access this platform in a variety of ways, allowing them to easily and swiftly configure parameters and send operational instructions to perform various functions.

Keywords: Paper documents; Sorting robot; Python; Human-computer interaction

Online publication: November 29, 2023

1. Introduction

Paper document sorting is done manually in many offices. Manual paper sorting not only requires a huge amount of manpower and material resources, but it is also not efficient and precise. Therefore, the use of robots has been a development trend in offices in various countries [1], and there have been several studies in this field. For example, automatic cigarette paper sorting and packaging equipment has been developed, which is composed of a conveying system, a palletizing system, a belt system, etc [2]. An intelligent sorting system for express packages based on barcode recognition has also been developed [3]. An automatic sorting system of material flow has been developed to reduce coordinate deviation and logistics sorting error rate of items captured by the existing system, and the system showed good results [4]. A robot capable of handling multiple items has been developed. This robot employs deep learning object detection and a 3D vision algorithm to guide the robot arm in grasping, classifying, and placing items. The primary objective of this research is to address challenges related to identifying irregular multi-items within cluttered and disorganized piles [5]. Moreover, a coin sorting and counting control system has also been designed to reduce the burden of manual coin counting and sorting and human errors [6]. In addition, a 3D printer based on a rectangular coordinate system has been developed, with a focus on optimizing the mechanical structure of the 3D printer for improved performance. Despite these advancements, there remains a relative scarcity of research in the area of paper sorting. Therefore, we developed a fully automatic paper-sorting robot.

2. Design scheme

In this project, we developed a fully automated paper document sorting robot, which was composed of hardware and software. To begin, the hardware components are constructed using aluminum profiles to create the framework in the form of a box truss gantry structure. This framework accommodates the installation of racks, linear guide rails, gears on the stepper motor, and rack clamps. These elements enable the slider on the linear guide rail to move along the X, Y, and Z axes, facilitating the three-dimensional movement of the manipulator. In addition, the mini vacuum pump is connected with the mini solenoid valve and the vacuum nozzle through a pneumatic tube, and the power supply of the mini solenoid valve is controlled by a relay to adsorb or release the paper. Secondly, the LubanCat 4 embedded development board is used as the motherboard of the electrical circuit. This board transmits pulse signals to stepper motor driver, driving the stepper motor. Additionally, a camera module is employed to identify the paper's position and capture images of the paper. A negative pressure sensor module is utilized to continuously monitor pressure levels in real-time, while a laser ranging module enables real-time measurement of the distance between the vacuum nozzle and the paper. Lastly, an artificial intelligence algorithm combined with a camera module is used to detect the position of the paper, identify the text on the paper, and build a human-computer interaction system based on the motherboard. Users can access the system through computers or mobile devices to control the sorting robot.

The operating procedure of the robot is as follows: The user selects the rules for classification or sorting in the human-computer interaction interface. After receiving the instruction, the motherboard coordinates various electrical circuits and drives the stepper motor to make the manipulator module reach the paper position. Then, the camera module identifies the content on the paper, the vacuum nozzle absorbs the corresponding paper, analyzes the content, and moves the paper to a specific position for release [8]. The overall structure of the sorting robot developed in this project is shown in **Figure 1**.

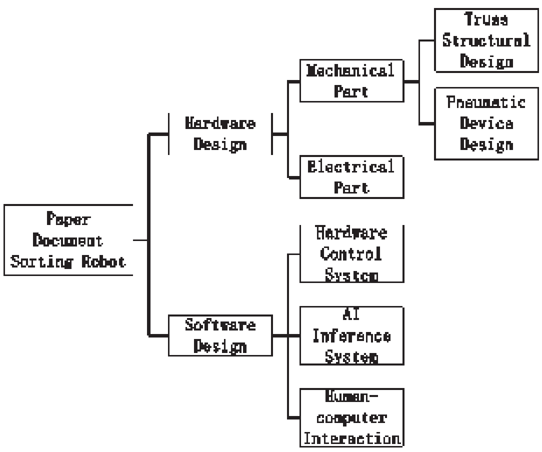

Figure 1. The overall structure of the sorting robot

3. Hardware design

The hardware design of this project was composed of mechanical part and electrical part. The mechanical part includes a truss structure design and pneumatic device, while the electrical part is composed of a LubanCat 4 embedded development board, truss structure control circuit, pneumatic device control circuit, manipulator module, etc. The manipulator module includes a camera module, a negative pressure sensor module, a laser ranging module, a micro switch, etc. Users can choose to connect with the motherboard by wired or wireless means, set parameters, and send operation instructions through the human-computer interaction interface. After receiving the instructions, the motherboard first instructs the camera to detect the position of the paper, controls the stepper motor on the X-axis and Y-axis to drive the mechanical structure, and runs the manipulator above the position of the paper. Then the camera and OCR model take a picture of the paper and identify the text. The Z-axis stepper motor then lowers the manipulator until the micro switch touches the surface of the paper document and triggers the stop signal. The solenoid valve is then opened so that the vacuum nozzle absorbs the paper and moves it to a specific position. Then, the solenoid valve closes to release the paper, completing the paper sorting task [9].

3.1. Mechanical part

3.1.1. Truss structural design

The mechanical structure of the paper document sorting robot developed in this project adopts a box-type truss gantry structure, which is built with European standard aluminum profiles and fixed with connectors and fasteners. Its structure is composed of three axes, X, Y, and Z, forming the space rectangular coordinate system. Its structure diagram is shown in **Figure 2**, AB and CD are the X-axes, EF is the Y-axis, and GH is the Z-axis. The X-axis is the horizontal axis of the truss structure, parallel to the ground and perpendicular to the Y-axis and Z-axis, which is used to control the left and right/lateral movement of the manipulator module. The Y-axis is the front and back axis of the truss structure, parallel to the ground and perpendicular to the X-axis and Z-axis, which is used to control the front and rear/longitudinal movement of the manipulator module. The Z-axis is the vertical axis of the truss structure, perpendicular to the ground, X-axis and Y-axis, which is used to control the up and down movement of the manipulator module. A rack and linear guide rails are installed on the X, Y, and Z axes, and a slider is installed on the linear guide rails. The X-axis sliders are connected with the Y-axis, and the Y-axis slider is connected with the Z-axis slider. The end of the Z-axis is connected with the manipulator, and the gear is installed on the output shaft of the three stepper motors, so that the gear is engaged with the rack. When the stepper motors rotate, the sliders can move on the X, Y, and Z axes. The truss gantry structure has the advantages of stable structure, large load-bearing capacity, and large free space.

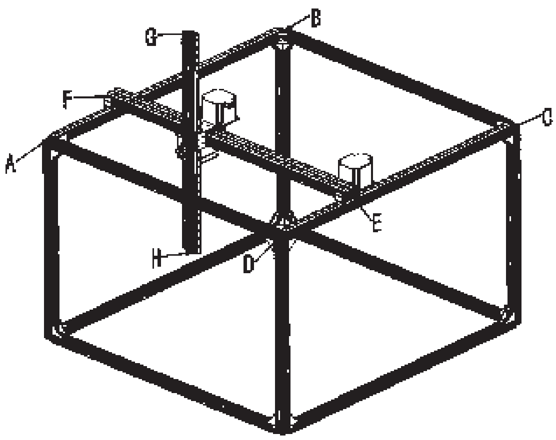

Figure 2. Truss structure diagram of sorting robot

The truss structure is driven by three stepper motors, as shown in **Figure 3**, and the transmission mechanism is composed of a gear, a rack, a linear guide rail, and a slider. The stepper motor can achieve very precise position control, with high torque and high stability, and its output shaft is connected to the gear, the gear is fastened to the rack on the aluminum profile, and the movement of the rack is controlled by the rotation of the gear, thus driving the movement of the truss structure. The linear guide rails are fixed on the aluminum profile, providing smooth and linear guidance and support for the truss structure. The sliders slide across the linear guide rails, allowing the truss structure to move along the linear track, while reducing friction and vibration, ensuring the precise position control and smooth movement.

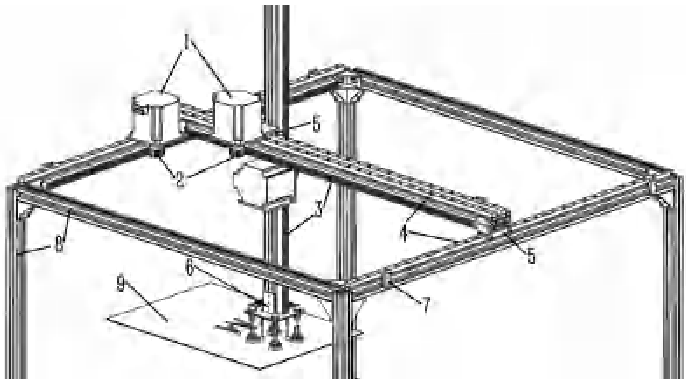

Figure 3. Assembly diagram of main parts of sorting robot. (1) Stepper motor, (2) Gear, (3)Rack, (4) Linear guide rail, (5) Slider, (6) Manipulator module, (7) Limit switch, (8) Aluminum profile, (9) Paper document

3.1.2. Pneumatic device design

The pneumatic device of this project is composed of a mini vacuum pump, a mini solenoid valve, a pneumatic tube, a vacuum nozzle, etc. A mini vacuum pump is utilized to create a negative pressure environment, and a mini solenoid valve is used to control the on-off of the air. The pneumatic tube is linked to the mini vacuum pump, the mini solenoid valve, and the vacuum nozzle for transmitting negative pressure, and the vacuum nozzle is responsible for generating the suction effect. The mini vacuum pump generates negative pressure, and the mini solenoid valve opens or closes accordingly. When it is necessary to adsorb paper, the mini solenoid valve opens, permitting the flow of air. The pneumatic tube transmits negative pressure from the mini vacuum pump to the mini solenoid valve, and then transmits it to the vacuum nozzle. The vacuum nozzle makes contact with the paper's surface and employs negative pressure to adsorb it. When it is time to release the paper, the mini solenoid valve is closed, stopping the flow of air. This action eliminates the negative pressure, causing the paper to be released. The flow chart of this process is shown in **Figure 4**.

3.2. Electrical part

3.2.1. Luban Cat 4 embedded development board

The Luban Cat 4 development board is used as the motherboard for this project due to its high performance. The system-on-a-chip model utilized is the Rockchip RK3588S, featuring four Cortex-A76 cores and four Cortex-A55 cores, along with MALI-G610 MC4 GPU cores, and operates at a main frequency of 2.4GHz. This configuration delivers 6Tops of computing power, effectively meeting the performance demands of the project's development and operational environments. Additionally, the board includes a 40PinGPIO pin, supporting a universal asynchronous receiver/transmitter, an inter-integrated circuit, a serial peripheral interface,a pulse width modulation, a USB-A interface, and an RJ45 Ethernet interface to fulfill the project's external hardware equipment requirements.

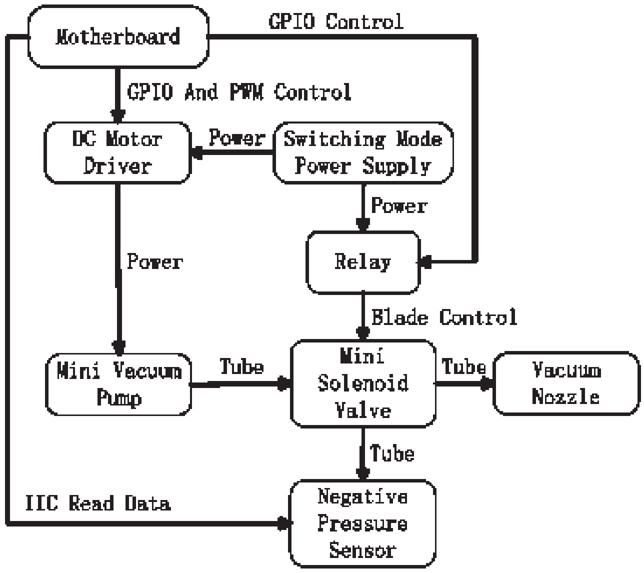

Figure 4. Design of pneumatic device

3.2.2. Truss structure control circuit

TB6600 stepper motor driver and 57BYG250B stepper motor are the power sources of the truss structure. Phase A and phase B of the stepper motor are connected to the driver respectively, and the control ENA, DIR, and PUL control pins of the driver are connected to the GPIO pins of the motherboard. The VCC and GND pins are connected to an external DC12V power supply, and the stepper motor can be enabled by writing a program to input a low level to the ENA+ pin. The forward or reverse of the motor is controlled by the DIR+ pin, and the PWM pulse signal can be sent to the PUL+ pin to control the motor rotation speed. The PWM waveform in a certain period, the greater the duty cycle, the faster the speed of the motor. Thus, different axes in the truss structure are controlled to move at different speeds and directions, and the connection of the truss structure control circuit is shown in **Figure 5**. As a trigger sensor, the limit switch is installed at both ends of the linear guide to limit the movement of the slider. The first is to ensure the operation accuracy and positioning accuracy of the machine. When the slider touches the limit switch, it sends a level signal to the GPIO pin of the main control board as an instruction to stop and align.

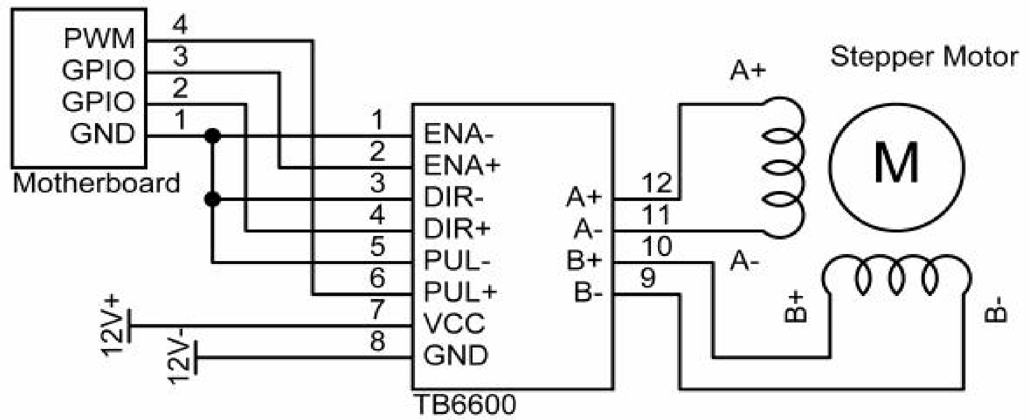

Figure 5. Truss structure control circuit connection diagram

3.2.3. Pneumatic device control circuit

The mini vacuum pump selected in this project has a DC12V DC motor built in, so the IC of model TA6586 is selected to drive the DC motor. The power supply of the DC12V mini solenoid valve is controlled by SRD-05VDC-SL-C relay. The control pin and relay of TA6586 are connected to the GPIO pin of the motherboard, as shown in **Figure 6**. The motherboard inputs PWM pulse signal to the BI pin of TA6586 and low level to the BF pin. The speed of the DC motor can change with the change of the PWM waveform, and the faster the speed, the stronger the suction of the mini vacuum pump. The common end of the relay is connected to the positive electrode of DC12V power supply, and one end of the mini solenoid valve is connected to the beginning of the relay, and the other end is connected to the negative electrode of DC12V power supply. When the GPIO pin output is low, the relay engagement and the mini solenoid valve is started.

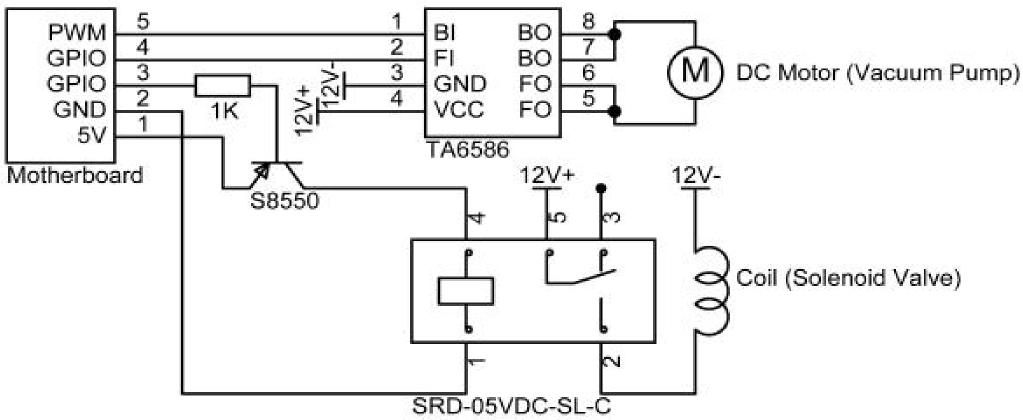

Figure 6. Pneumatic device control circuit connection diagram

3.2.4. Manipulator module

This project independently designs a manipulator module, including manipulator module bracket, vacuum nozzle, micro switch, spring, limit switch, camera module, laser-ranging module and negative pressure sensor and other devices. The manipulator module is shown in **Figure 7**.

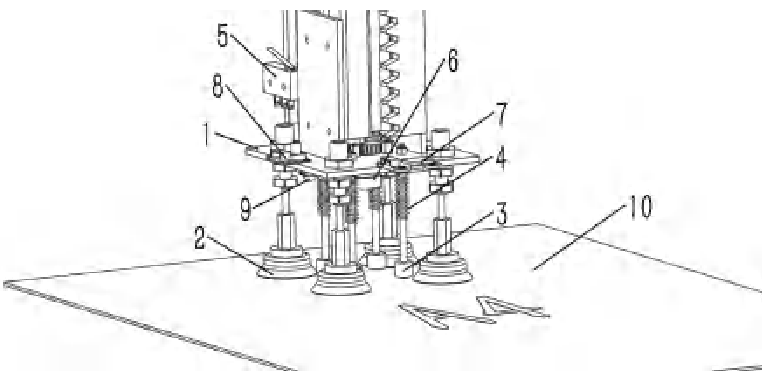

Figure 7. Schematic diagram of manipulator module. (1) Manipulator module bracket, (2)Vacuum nozzle, (3) Micro switch, (4)Spring, (5) Limit switch, (6) Camera module, (7) Laser-ranging module, (8) Negative pressure sensor, (9) Fill light, (10) Paper document

3.2.4.1. Camera module

This project uses HD USB free drive 120FPS, 2MP camera module. The camera module is installed in the manipulator and connected to the motherboard via USB, the camera is invoked by the program, combined with the You Only Look Once (YOLO) model to detect the position of the paper, combined with OCR to identify the text on the paper.

3.2.4.2. Negative pressure sensor module

This project uses the RSCM17100KN090 negative pressure sensor module. The negative pressure sensor module has a measurement range of -90 KPa to 0 KPa. The control pin of the module is connected to the motherboard, and the module will return the negative pressure value of the mini vacuum pump to the motherboard in real time. When the paper is absorbed or released abnormally, the system will automatically adjust the speed of the motor of the vacuum pump according to the negative pressure value. The principle of the negative pressure sensor module is shown in **Figure 8**.

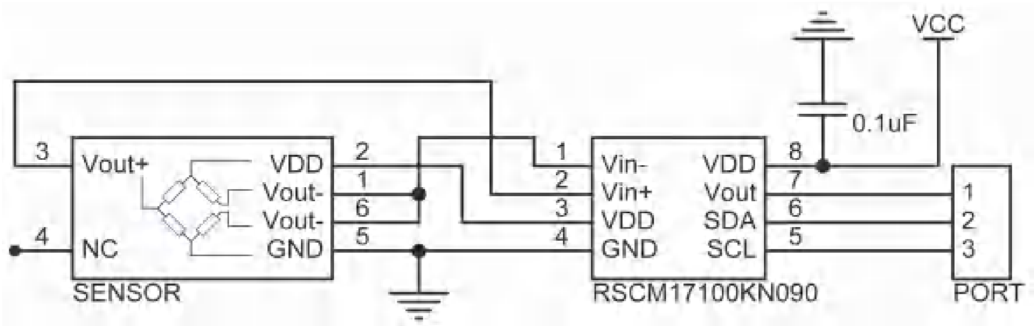

Figure 8. Schematic diagram of the negative pressure sensor module

3.2.4.3. Laser ranging module

The TOF050F laser ranging module is selected for this project. The laser ranging module is installed in the manipulator, and the control pin of this module is connected to the motherboard by the program to read the distance between the vacuum nozzle and the paper in real time.

3.2.4.4. Microswitch

The micro switch acts as a trigger sensor, which is installed in the manipulator and used to detect the contact or departure of the object to generate a high-low level signal input to the motherboard. As the manipulator descends and makes contact with the paper or the surface, a micro switch is activated, preventing the manipulator from moving any lower. The motherboard receives the signal indicating that the switch has been triggered, allowing it to halt the downward movement of the stepper motor.

4. Micro switch

The software design component of the project uses a Linux operating system as its base, with the programming implemented in Python language. The program is composed of hardware control system, artificial intelligence reasoning system, and human-computer interaction system. The hardware control system, and various external hardware, such as motor drive modules, relays, sensors, etc., are connected to the GPIO pins on the motherboard, and their operation is controlled by the program. The software includes an AI inference system that utilizes the YOLO deep learning object detection framework in Python. This system is connected to a camera, and configured to load a pre-trained YOLO model for paper position detection. It also incorporates Optical Character Recognition (OCR) models for text recognition on the paper, as well as Natural Language

Processing (NLP) models for processing natural language, including tasks like sentiment analysis, text classification, and text summarization. Additionally, there is a human-computer interaction system that employs HTML5, CSS, and JavaScript to create the web front-end. The Flask framework is used to construct the web-based human-computer interaction interface, which users can access via the IP address of the main control board within the same LAN [10]. The workflow of the software part is shown in **Figure 9**.

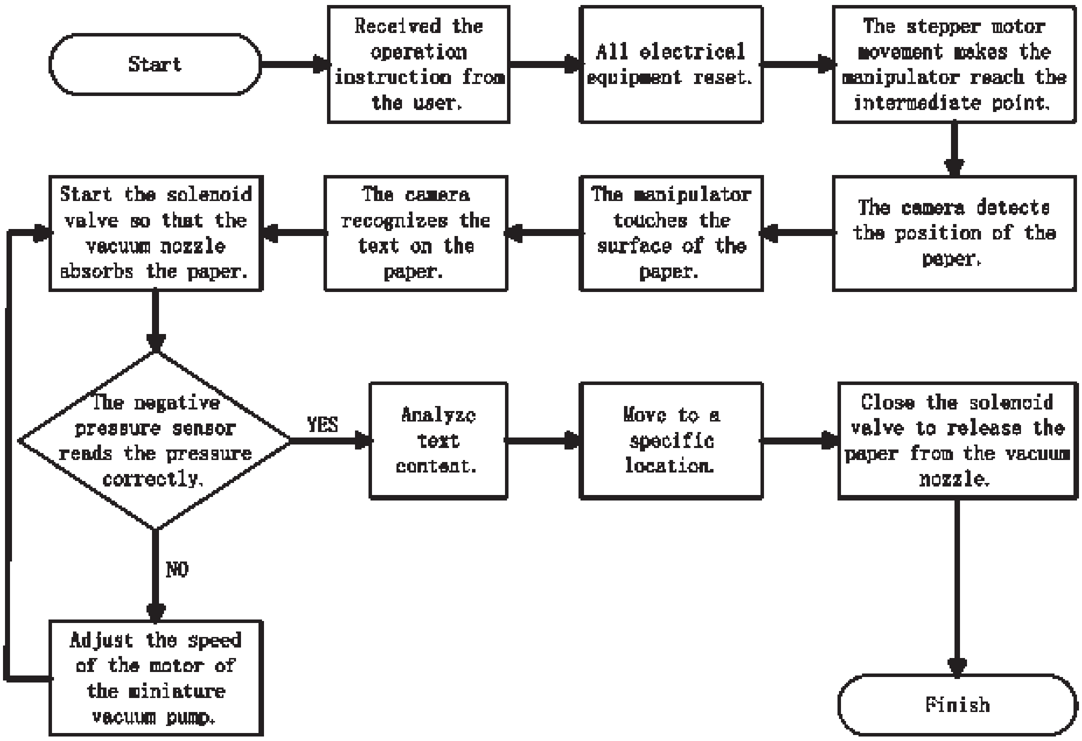

Figure 9. Flow chart of software

5. Conclusion

The paper document sorting robot developed in this project boasts a high level of automation, enabling efficient and precise sorting and classification of paper documents. It reduces the need for manual intervention and can even operate unattended, resulting in a significant improvement in document processing efficiency. This robot can rapidly process large volumes of documents while drastically reducing classification errors. It features a straightforward user interface, making it easy to operate, and is suitable for diverse scenarios, including libraries, archive rooms, and office environments. Furthermore, the project is highly scalable for future development, allowing for the addition of related devices and the creation of more practical functions. It can also be customized and expanded to cater to specific user requirements.

Disclosure statement

The authors declare no conflict of interest.

Funding

This work was supported by the Guangdong University Scientific Research Young Innovative Talents Project (Natural Science) under Grant 2021KQNCX240 and Zhanjiang Preschool Education College 2023 College Students Innovation and Entrepreneurship Training Program under Grant 2023ZYDC02.

References

[1] Rahman MO, Hussain A, Basri H, 2014, A Critical Review on Waste Paper Sorting Techniques. International Journal of Environmental Science and Technology, 11(02): 551–564.

[2] Luo Y, Jiang J, Zhou J, 2011, Research and Development of Automatic Cigarette Paper Sorting and Packaging Equipment. Packaging Journal, 3(03): 57–60.

[3] Zhang F, 2022, Design of Intelligent Sorting System for Express Packages Based on Barcode Recognition, dissertation, University of Science and Technology Liaoning.

[4] Li J, 2023, Design of Logistics Automatic Sorting System Based on Machine Vision. Automation Technology and Application, 42(08): 34–37 + 41.

[5] Wu S, 2023, Research on Random Sorting Robot of Many Irregular Items. Industrial Control Computer, 36(08): 69–71.

[6] Xie F, Kong C, 2023, Coin Sorting Counting Control System Design. Mechanical and Electrical Information, 2023(18): 36–39.

[7] Liu H-S, 2023, Mechanical Structure Design of 3D Printer Based on Rectangular Coordinate System. Automation Application, 64(05): 1–3.

[8] Gottschling A, Schabel S, 2016, Pattern Classification System for the Automatic Analysis of Paper for Recycling. Int. J. of Applied Pattern Recognition, 3(01): 38–58.

[9] Rahman MO, Hussain A, Scavino E, et al., 2014, DNA Computing Algorithm for Recyclable Waste Paper Sorting. Computer Systems Science and Engineering, 29(05): 361–374.

[10] Rahman MO, Hussain A, Basri H, 2020, Automated Sorting of Recycled Paper Using Smart Image Processing. Automatisierungstechnik, 68(04): 277–293.