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Development of Rail Precision Cleaning Vehicle for Modern Tramway

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Abstract. Supported by the Zhuhai Collaborative Innovation Project, we develop a Road-Rail Precision Cleaning Vehicle for the rail of the first modern tramway based on the Tram Wave system in China, which has been built in Zhuhai City. Development scheme of overall mechanical structure, electrical control and condition monitoring system and man-machine interface system has been realized. We also designed a target recognition algorithm based on OpenCV to control actuators like solenoid valve, electromagnetic clutch and air pressure regulating valve and so on.

1. Introduction

As a mean of energy-saving, pollution-free and low-input public transport, modern trams have developed rapidly in China in recent years. The rails of modern tramway are generally laid on city roads, sharing road rights with household-use cars. Among them, embedded Groove Rail is the most common type of rail[1]. After long-term use, natural garbage such as sand, muck, leaves, dust, iron filings, domestic garbage from pedestrians and vehicles such as plastic bag, plastic bottle, scrap paper and lint, adhesive garbage such as freestone, residue soil will accumulate in the rail. These kinds of garbage will not only corrode the rail, but also affect the safety of trams in serious cases.

At present, the rail cleaning of tramway in the world is mainly based on manual cleaning. It's time-consuming, inefficient, dust-polluting, which is not a good fit for the long-term development of modern tramway[2]. Depending on the national rail construction standards, rail cleaning vehicles are generally only suitable for use in the specific regions, and most of them are not highly automated[3].

In order to help solving this dilemma for Zhuhai Chengjian Modern Transportation Co. Ltd., we have developed the Rail Precision Cleaning Vehicle based on the current cleaning vehicle model. This design enables the implementation of rail cleaning for the first modern tramway in China, which it is equipped with the Tram Wave system and has been built in the Zhuhai city [4].

2. Mechanical structure development

The vehicle includes a Road-Rail Vehicle and a vehicle control system, whose structure is shown in Figure 1. Road-Rail Vehicle was remodelled by a Chinese National Heavy-Duty Truck Ace Series Commercial Freight Car with modified rail devices. In addition, the vehicle includes 2 high-speed



cameras and various types of testing equipment for observing the status of the freight car, such as sewage water level detection, clean water level detection, oil pressure detection and so on.

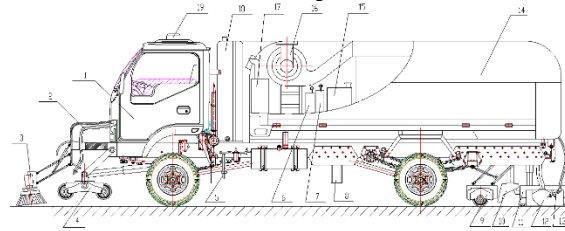


Figure 1. General structure (1- freight car, 2- front low pressure dust waterway, 3- front brush, 4- front rail guide, 5- high speed camera, 6- low-pressure diaphragm pump, 7- high-pressure plunger pump, 8- water rinsing gun, 9- rear rail guide, 10- third rail suction, 11- groove rail cleaning device, 12- groove rail suction, 13- groove track high-pressure waterway, 14- sewage tank, 15- hydraulic pump and fuel tank, 16- fan, 17- diesel sub-engine, 18- clear water tank, 19- alarm)

3. Design of electrical control system

3.1. Partial hardware configuration

The power of the vehicle is provided by a diesel sub-engine. We use the solenoid valve to achieve the on and off of oil and waterway in hydraulic and water systems[5]. In addition, the vehicle is equipped with the air pressure regulating valve, the push button switch, the high-pressure water gun, sensors and so on.

3.2. Design of control circuits

3.2.1. Overall plan of control system. We use PLC as the core of control system[6]. We set a start switch signal, a front switch device and a rear switch device limit switch signal as input signal. We also set an air pressure regulating valve current control signal, an electromagnetic clutch control signal, an electric diaphragm pump control signal and a solenoid valve control signal as output signal.

3.2.2. Integrated control scheme block diagram of control system. Control system includes the regular cleaning mode, the precision cleaning mode and the condition monitoring system. The integrated control scheme block diagram of Control System is shown in Figure 2.

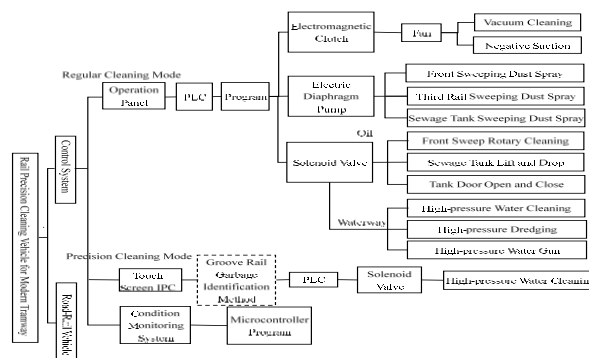


Figure 2. Integrated control scheme block diagram of control system

3.3. Regular cleaning mode

3.3.1. Hardware selection and control object. PLC selection is an important part of the design of control system. After determining actions required by the control object, we carry out the assignment of input and output. We choose a CPU226DC/DC/DC transistor output PLC in the Siemens S7-200 series, a 4-

point input plus 4-point output EM223 digital input expansion module and a 2-point output EM232 analog output expansion module.

3.3.2. Design of electrical control system process. The cleaning process of the vehicle includes the Road-Rail changing, the rail and the power belt cleaning and the garbage collecting. The flow chart of working process is shown as Figure 3.

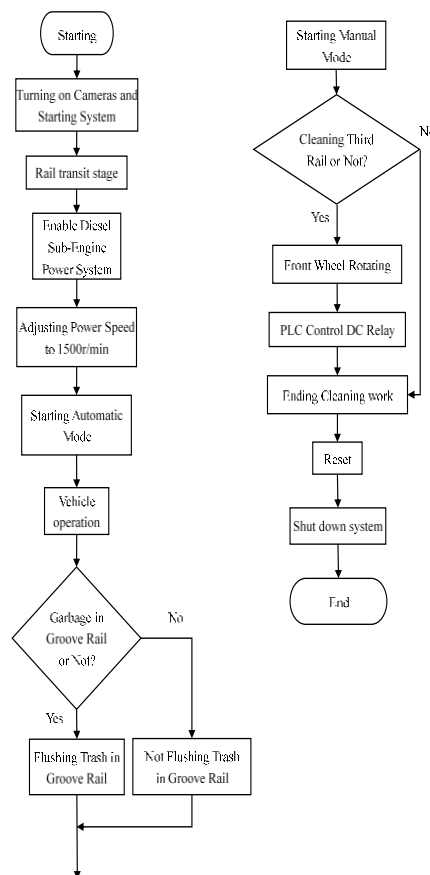


Figure 3. Flow chart of working process

3.3.3. Design of PLC programming. According to the flow, PLC ladder program that we designed includes the communication program, the physical button main program, and the touch-screen industrial personal computer (IPC) virtual button program.

- **Communication program.** The touch-screen IPC is used as the upper computer, and PLC is the lower computer, which means PLC is the slave station.
- **Physical button main program.** We select manual mode or automatic mode by inputting signals I0.0 and I0.1 and use the rising edge switch of stop switch I2.0 to reset the output signal except the high-pressure backwater signal, the intermediate relay and the input register.
- **Touch-screen IPC virtual button program.** The touch-screen IPC is an inductive liquid crystal display device that can receive input signals[7]. When the virtual button on the screen is touched strongly, the on-screen tactile feedback system can drive various linkage devices according to the pre-programmed program, which can be used to replace the mechanical button control panel.

3.4. Precision cleaning mode

3.4.1. Hardware selection. We first use the touch-screen IPC mentioned to run the MFC graphical interface program and the OpenCV machine vision program. Then we select the industrial high-speed camera compatible with Windows operating system and OpenCV software. We also have an additional lens for the industrial camera.

3.4.2. Software solution. The precision cleaning control system program includes the touch-screen IPC program and the machine vision program. Finally, we need to integrate two programs into one operation interface and communicate with the lower computer program to achieve automatic and precise cleaning.

(1) Design of groove rail garbage identification method

We use OpenCV software for program development, the design scheme is shown in Figure 4. The focus is on the detection accuracy and detection efficiency.

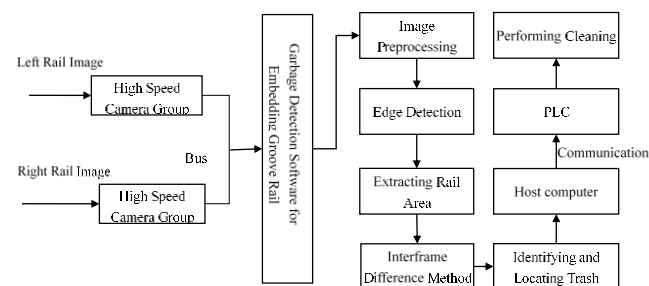
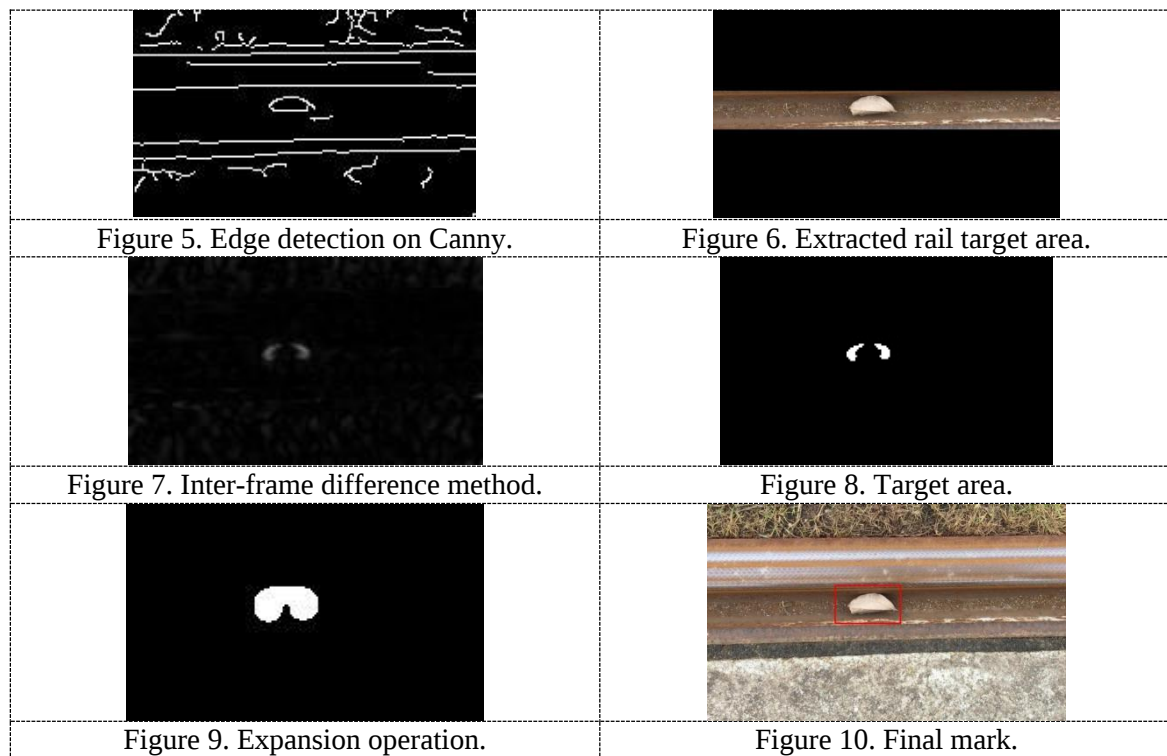


Figure 4. Design scheme of groove rail garbage identification method

- *Pre-processing the collected image.* We use the weighted average method, the bilinear interpolation algorithm, the combination of median filtering and Gaussian filtering to get the feature data of the grayscale and groove rail.
- *Conducting edge detection.* We perform the Canny operator edge detection to mark and identify those pixels in the digital image, reduce the amount of data and also obtain all the edge data that may exist, as shown in Figure 5.
- *Extracting the rail area.* We use the Hough transform line detection algorithm[8] to detect the line edge of the rail. Then we take the position of groove rail in the image, which are the two straight lines at the top and bottom of groove rail. The extracted rail target area is as shown in Figure 6.
- *Identifying and locate garbage[9].* The inter-frame difference method is selected to get the final target area as shown in Figure 10. In order to reduce the cavity effect, we expand the target area. The processing result is as shown in Figure 9.
- *Getting garbage coordinates and perfume cleaning.* We retrieve the outline of the expanded target area to calculate the centroid through contour moments and centre coordinates. The target of the final mark is as shown in Figure 10.



(2) Design of touch-screen IPC program

We use Visual Studio platform to develop programs by building an MFC project. When a button is pressed, MFC program will use the CByteArray class serial control signal supporting the dynamic establishment of the array in bytes and the information transmission function under the MSCOMM control to send combined control information to PLC and perform an operation.

We also set up a Cyclic Redundancy Check Algorithm (CRC). Only when CRC check code calculated by PLC using the ladder diagram is consistent with the check code sent by the host computer, the control information is considered valid, and then the data is stored in the data buffer area.

3.5. Design of condition monitoring system

The condition monitoring system enables monitoring of the environment inside and outside the vehicle. We transfer the collected data to the user interface on touch screen IPC for real-time display and store it in the database. If a parameter is found to be abnormal, the system will automatically alarm in time to record the alarm time and the specific alarm cause, which is convenient for us to view and maintain later.

4. Conclusion and outlook

According to the actual needs, we develop Rail Precision Cleaning Vehicle based on China National Heavy-Duty Truck Ace Series Commercial Freight Car's Road-Rail Vehicle for the cleaning of modern tramway's groove rail in Zhuhai City. Our work combines PLC and touch-screen IPC to realize automatic cleaning of image recognition, which makes the development of the vehicle reasonable. The vehicle has high degree of automation, high reliability and stable work, which greatly improves the efficiency of cleaning the rail and reduces the consumption.

Rail Precision Cleaning Vehicle that we develop adopts the cleaning method of high-pressure water flushing rail, which will cause water consumption to a certain extent. However, combined with image recognition technology, the vehicle can achieve precise cleaning effect and improve water utilization efficiency. The image recognition technology fails to realize the classification of garbage. In the future, deep learning can be used to realize the garbage classification of image recognition. In addition, although Road-Rail Vehicle has a low manufacturing cost, the maintenance may be troublesome. We are

considering replacing the vehicle with the electric rail flat car, which is also in line with the government's slogan of industrial energy saving and greening.

Acknowledgments

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