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DESIGN OF DRAINAGE PIPE INTELLIGENT INSPECTION VEHICLE BASED ON THE ARDUINO PLATFORM

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ABSTRACT

Urban drainage systems rely heavily on drainage pipes for efficient operation. Regular inspections and maintenance are necessary to ensure optimal functioning. However, due to their complex underground structure and hazardous internal conditions, manual inspections are inefficient and dangerous. One of the most effective solutions for inspecting drainage networks is the use of pipe inspection robots. Based on the characteristics and requirements of pipeline inspection, an intelligent inspection vehicle was designed using Arduino UNO R3 as the main control system. Through the functionality and development of the Arduino platform, the intelligent inspection vehicle for drainage pipes has a compact and functional overall structure, indicating promising application prospects.

KEYWORDS: *Drainage Pipe, Arduino, Intelligent Inspection Vehicle*

INTRODUCTION

Drainage pipe networks are essential infrastructures for the environmental safety of modern cities. By the end of 2022, China's drainage pipe network is set to exceed a length of 900,000 km, with an annual discharge of 63.8 billion m^3 of sewage.[91] Frequent accidents occur in China's municipal drainage network due to structural aging and dynamic environmental changes. Problems such as fractures, blockages, and corrosion of drainage pipes have a severe impact on the sewage system's functioning and the citizens' safety. With the urban expansion, municipalities face unprecedented challenges in maintaining their drainage networks. Although there are commonly used pipeline inspection methods that involve human intervention, inspecting drainage pipes proves difficult due to their intricate underground design. Additionally, sewage accumulates and undergoes fermentation inside the pipes, producing toxic and harmful gases, including hydrogen sulfide (H_2S) and carbon monoxide (CO). This increases the danger associated with manual inspection.[2]

Addressing current challenges in the manual inspection of drainage pipes and under the context of IoT(Internet of Things) technology, there is a growing trend of replacing manual inspection with intelligent equipment for drainage pipe inspection. To meet the demands of this trend, a drainage pipe intelligent inspection vehicle, referred to as the intelligent inspection vehicle, has been designed in this paper based on the Arduino platform. The intelligent inspection vehicle incorporates AI (Artificial Intelligence) technology, IoT (Internet of Things) technology, and robotic technology. It offers numerous benefits, including streamlined integration, heightened detection efficiency, and simplified operation, especially

when compared to manual inspection.

1. OVERALL ARCHITECTURE DESIGN

The design of the intelligent inspection vehicle has the following functions. Firstly, by utilizing the Arduino platform for function development and integration of multiple modules, the overall operation of the vehicle is normalized. Second, the intelligent inspection vehicle is controlled using wireless connection devices, including the PS2 receiver, handle, and WiFi connection module. Additionally, the WiFi module has the capability to transmit information for other functional modules. Thirdly, the intelligent vehicle's driving attitude and position are transmitted to the host computer using the ultrasonic obstacle avoidance and inertial navigation sensors, thereby enabling safe operation. Fourthly, the internal condition of the drain is assessed for damage and potential risks using high-definition cameras, infrared thermal imagers, and gas sensors. Fifthly, the power supply, motor and mecanum wheels which form the drive module guarantee the driving power and agility of the intelligent inspection vehicle.

Based on the functional specifications of the smart inspection vehicle, the design of each system module is carried out. The hardware components predominantly comprise of an ultrasonic distance measuring module, an obstacle avoidance module, a detection module, an information transmission module, a positioning and balancing module and a drive module (displayed in Figure 1).

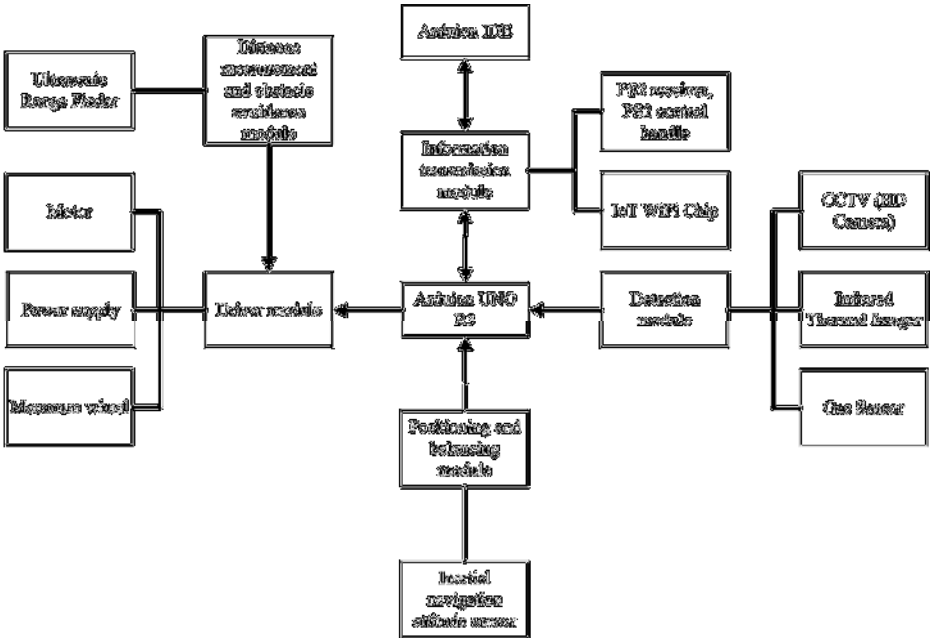
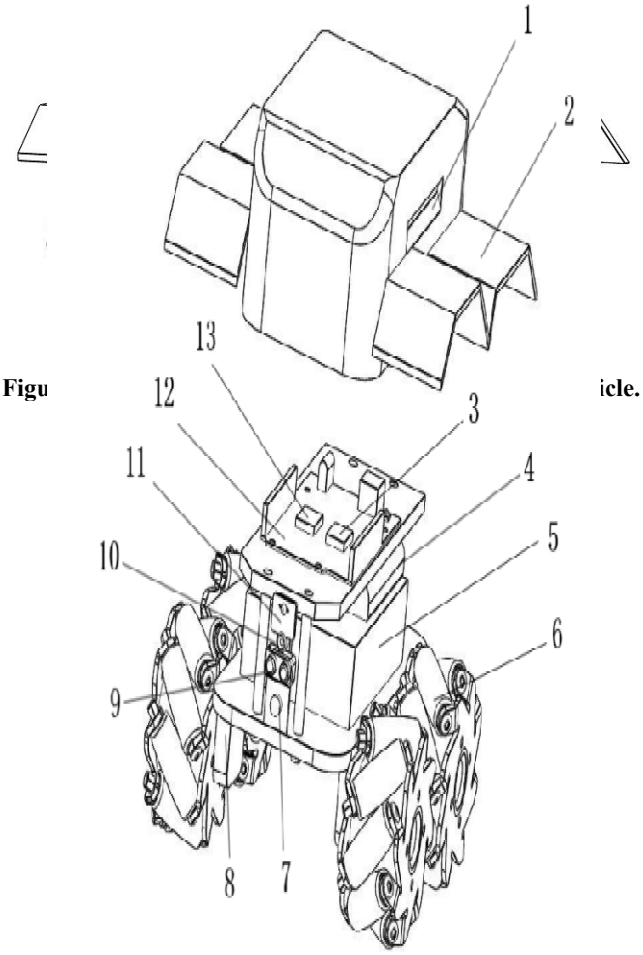


Figure 1: Overall Design Framework Diagram.

2. HARDWARE MODULE DESIGN

Once the overall design plan is settled upon, a comprehensive structure for the intelligent inspection vehicle is developed, with the selection of suitable hardware components, encompassing the design of the vehicle body and sensor placement, the main control and positioning communication chips, the motor, and the power source, among others. The intelligent inspection vehicle's body is fitted with an acrylic waterproof shell, waterproof baffles positioned above the wheels to

provide added protection for the inspection equipment housed inside the vehicle, and grooves on either side of the body to facilitate lifting the hooks while the vehicle moves in and out of the drainage pipe vertically (as shown in Figures 2 and 3). This chapter will explicate the inte .



Figu icle.

Figure 3: Overall View of the Intelligent Inspection Vehicle.

[1].Groove [2].Waterproof Baffle [3].Iot Wifi Chip [4].PS2 Receiver [5].Power Supply [6].Mecanum Wheel [7]. Gas Sensor [8].Motor [9].Ultrasonic Module [10]. Infrared Thermal Imager [11]. High-Definition Camera [12].Arduino UNO R3 [13].Inertial Navigation Attitude Sensor)

2.1 Ultrasonic Ranging And Obstacle Avoidance Module

Ultrasound is a special kind of mechanical wave, the wavelength is very short, in the air is generally shorter than 2 cm, and the wave characteristics determine that it must rely on the medium to propagate. Ultrasound is widely used in industrial scenarios such as cleaning, inspection, sterilization, and disinfection. Ultrasonic distance measurement is one of the technical applications of the ultrasonic principle, which is realized by using the property of ultrasonic waves to be reflected by obstacles. Ultrasonic ranging works by triggering ranging through IO port Trig, sending out a high-level signal,

stopping the timing when the receiver receives the return signal, and calculating the distance based on the propagation speed of the sound wave in the air.

To achieve the distance detection and obstacle avoidance functions of the detector vehicle, the design incorporates the HC-SR04 ultrasonic range finder as its central module. HC-SR04 can be developed on various microcontroller platforms, and its measured results are accurate within the acceptable working condition errors of different application scenarios. Following thorough testing, the module has demonstrated excellent compatibility with the Arduino main control board, enabling reliable range measurement and obstacle avoidance functions to be realized in standalone experiments.

2.2 DETECTION MODULE

2.2.1 CCTV Detection Module

The CCTV (Closed Circuit Television) inspection system is one of the primary camera vision-based technologies for inspecting pipes used for drainage. The utilization of high-definition cameras allows for a thorough analysis of the pipe structure. Additionally, software systems are used to determine the existence of rust, scaling, corrosion, and cracking, as well as to identify structural and functional defects within the pipeline.[3] Technological advancements have enabled the camera to capture higher-quality image data, thereby improving the precision of pipe visual inspections.

The inspection component of this design features a Sentry 2 high-definition camera that is accompanied by an LED light. Various recognition outcomes can be achieved by illuminating the environment with different colors of light, which allows for adaptable inspection in diverse surroundings. Given the outstanding proficiency of deep learning in computer vision tasks, deep learning-based approaches have been incorporated into detecting surface defects within civil infrastructure, like drainage pipes. This module can accomplish not only direct image acquisition, but it can also undertake programming and development on the Arduino IDE platform through the ESP8285-WiFi chip onboard to achieve cloud image recognition, wireless image transmission, and other applications.

2.2.2 Infrared Thermal Imaging Detection Module

Infrared thermographic non-destructive testing technology is capable of detecting defects such as cracks in metals, non-metals, and composite materials. Its benefits include being non-contact, having a large detection area, quick inspection speed, and online detection. The novelty of infrared thermographic non-destructive testing technology lies in the use of infrared temperature measurement, which does not require physical contact with the object being measured and does not disturb the temperature field. The technology enables an intuitive and precise mapping of a two-dimensional temperature distribution of an object through thermal imaging. This method reveals important physical properties of the material located beneath the object's surface, as reflected by changes in surface temperature, and can ultimately determine an object's state.[4]

To achieve the function of infrared thermal imaging flaw detection, this design utilizes the MLX90640-D110 infrared thermal sensor as its functional module. The module has a thermal imaging resolution of 32×24 pixels and utilizes the MLX90640 far-infrared thermal sensor array to precisely detect the unknown area and temperature range of the target object. The field of view (horizontal viewing angle × vertical viewing angle) is 110° × 75°, and the radiation angle is suitable for close-range measurements. Its small size allows for easy integration onto the development board of an intelligent detection vehicle.

By using a combination of high-definition camera inspection module image acquisition, deep learning development, and infrared thermal imaging flaw detection module, drainage pipeline inspection can be carried out with greater comprehensiveness, accuracy, and complementarity.

2.2.3 Gas Detection Module

Sewage can accumulate and ferment within pipelines, resulting in the generation of a combination of toxic and harmful gases. This gas mixture typically consists of methane (CH_4), oxygen (O_2), hydrogen sulfide (H_2S), carbon dioxide (CO_2), ammonia (NH_3) and carbon monoxide (CO). Inhalation of these gases can cause irritation to the respiratory system and eyes, thereby increasing risks related to manual work. Therefore, it is crucial to install gas sensors for inspecting pipelines. These sensors can provide precise data which can aid in decreasing accidents when inspectors need to enter the pipeline.

The module utilizes an MQ-4 gas sensor, with the gas-sensitive material incorporating tin dioxide (SnO_2) which exhibits low conductivity when in contact with clean air. It demonstrates strong methane sensitivity across a wide concentration range, rendering it highly advantageous due to its low cost, long lifespan, and a straightforward driving circuit. Furthermore, the MQ-4 gas sensor is highly sensitive to methane and possesses strong anti-interference traits against alcohol and other interfering gases. When combustible gas is present in the environment surrounding the sensor, its conductivity rises proportionately with the concentration of gas in the air. This change in conductivity can be translated into an output signal correlating to the gas concentration via a basic circuit. To cater to alterations in pipeline inspection environments and demands, inspectors have the option of selecting various models of MQ series gas sensor products suitable for different scenarios.

2.3 INFORMATION TRANSMISSION MODULE

2.3.1 PS2 Connection Module

The PS2 connection module mainly consists of two parts: the PS2 handle controller and the PS2 receiver. The PS2 handle controller is the user's interactive terminal and the "dialogue window" between the user and Arduino. The PS2 signal receiver has a total of 9 pins. According to the physical pin assignment, from left to right, they are DI/DAT, DO/CMD, empty port, GND, VDD, CS/SEL, CLK, empty port, and ACK. The DI/DAT and DO/CMD pins are the flow ports from the handle to the microcontroller and the microcontroller to the handle respectively, and belong to the full-duplex communication mode. The CS/SEL pin provides the handle trigger signal and is placed low during normal communication. Unlike the PS2 handle controller, the PS2 receiver mainly plays an important role in communication and data transmission during the interaction with the Arduino main control board.

The intelligent inspection vehicle needs to complete various movement modes and speed control, mainly by reading the button information or remote control information sent by the PS2 handle. For example, the PS2 handle is responsible for transmitting button information, and the PS2 receiver is connected to the Arduino development board to receive handle information. When the microcontroller receives the handle information, it will send the set control information to the motor driver, thereby driving the motor to rotate and drive the Mecanum wheel to achieve multi-directional movement of the intelligent inspection vehicle.

2.3.2 WIFI Communication Module

The intelligent inspection vehicle operates within the drainage pipe, imposing several limitations on its communication

with the external environment. The use of tow cable communication may impede the movement of the robot significantly.[5] Thus, besides employing PS2 for module operation, an IoT WiFi chip is also utilized to improve the stability of information transmission. The intelligent inspection vehicle communicates with the control terminal outside the pipeline via the ESP8266 WiFi wireless transceiver module. The received control instructions are transmitted by the WiFi module to the main controller for analysis and actuation on other functional modules, thereby changing the operating state of the intelligent inspection vehicle. The ESP8266 wireless module offers affordable pricing, compact packaging, and low energy consumption as key advantages. This module has gained significant popularity in recent years within embedded and IoT (Internet of Things) development. This module enables Internet communication between the robot and the host computer through a WiFi wireless network, thereby achieving remote control of the intelligent inspection vehicle.

2.4 Positioning and Balancing Module

Real-time transmission of location information is critical for intelligent inspection vehicles. If an obstacle or damaged pipe is found during the inspection, the inspectors can immediately lock the position of the intelligent inspection vehicle through the positioning system, and combine the movement posture of the intelligent inspection vehicle obtained by the attitude sensor and the camera image feedback to determine the next instruction to send. The positioning and balance module of this design utilizes a WTGAHRS3-485 inertial navigation attitude sensor. The output includes acceleration, angular velocity, time, angle, longitude, latitude, and ground speed. This product is a high-performance three-dimensional motion attitude measurement system that relies on advanced MEMS technology. This module can achieve a synchronized output of GPS and attitude sensor information while integrating the heading angle with IMU data. It can still output accurate heading angle and longitude and latitude data without a GPS signal.

This module boasts high stability and integration of gyroscopes and accelerometers with high precision. It utilizes advanced microprocessors for dynamic calculation, implementing Kalman dynamic filtering algorithms to solve real-time motion posture efficiently. It comprises motion sensors like a three-axis gyroscope, a three-axis accelerometer, and a GPS+BD module (which is compatible with U.S. GPS satellite navigation and China's Beidou satellite navigation). The device offers precise and dynamic real-time compensation of three-axis attitude angles. Its diverse range of data configurations caters to various positioning and balancing functions in different scenarios throughout the pipeline.

2.5 DRIVER MODULE

2.5.1 Motor

The DC reduction motor comprises a DC motor and a reduction box. Two welding points are located at the end of the DC motor to enable the motor to rotate in both forward and reverse directions. The DC reduction motor boasts a compact and tight structure, small size, low energy consumption, and exceptional performance. This design incorporates an N20 reduction motor, which possesses distinctive performance features, such as a compact structure, versatile performance, and diminutive footprint whilst providing abundant torque. It is enclosed with a metallic casing and is resistant to corrosion. The gear exhibits excellent resistance to wear and tear post mechanical grinding and heat treatment. Furthermore, it boasts longevity and low levels of noise.

The output shaft of the N20 reduction motor adopts a flat output shaft design. The metal material ensures stable output torque and prevents slippage between the wheel and the output shaft, ensuring that the torque can be accurately transmitted to the Mecanum wheel. In this design, the Mecanum wheel and the output shaft of the N20 reduction motor are

connected by a coupling. On the one hand, this design facilitates the smooth transmission of torque, and on the other hand, it is considered that the motor output shaft should be in the same direction as the axis of the wheel hub.

2.5.2 Power Supply

In this particular design, the sensor detection module and power drive module have a working voltage range of between 3V and 8V. Thus, the selected battery discharge voltage must also be within this specified range. The chosen battery is a 5550mWh rechargeable 18650 lithium battery, which allows for both charging and discharging. The battery cell exhibits stable performance, low internal resistance, and an explosion-proof design, markedly reducing the potential for short-circuiting the battery upon encountering collisions or impacts. It boasts a high-rated short-circuit voltage (3.7V or 3.2V per single unit), enabling prolonged operation of external devices, and delivers stable power supply performance. This power source is specifically designed to support the regular operation of an intelligent detection vehicle.

2.5.3 Mecanum Wheel

The current vehicle chassis is entirely made of aluminum alloy plates, with a Mecanum wheel structure comprising four wheels. The intelligent inspection vehicle's wheels are arranged in pairs, with two wheels turning left and two turning right to create an X-shaped formation. The wheels of the intelligent inspection vehicle are mainly composed of hubs, rollers, and roller shafts.[6] The hub is a support frame, the rollers are arranged parallel to each other at an angle of 45° to the hub, and all wheels are driving wheels. When the hub rotates in the same direction, the rollers and the ground exert a friction force opposite to the rolling direction of the wheel hub, impeding its rotation. The Mecanum wheel employs a four-wheel drive and is coupled to the motor fixed on the base plate. Each Mecanum wheel is independently powered by its motor, providing improved driving force, stability, and security during movement (as shown in Figure 4).

The Mecanum wheel has the ability to regulate the velocity of different wheel components, indirectly, by adjusting the angle between the hub axis and the driven wheel axis. In addition, it can maneuver the whole car body in multiple directions using a precise installation method and the composition and decomposition of parallelograms of force. The mode of mobility for a Mecanum wheel-equipped car body is relatively comprehensive. This technology can execute the conventional front and back movements of traditional wheels and additionally, perform lateral movements and diagonal movements offset by 45° in the XY axis direction. The benefit of having multiple modes is that it can provide a diverse set of options to ensure the flexibility of movement of the vehicle body, especially in narrow pipes or wall cavities.

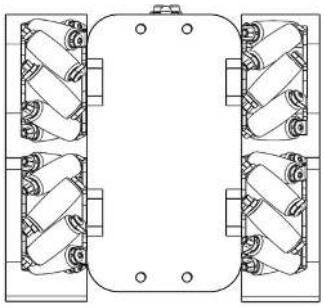


Figure 4: Bottom View of the Intelligent Inspection Vehicle.

3. DEVELOPMENT PLATFORM AND MAIN PROGRAM DESIGN

3.1 Development Platform

This design is centered around the Arduino ecosystem, comprising hardware and software. Hardware denotes the circuit framework constructed on the Arduino platform and linked to diverse electronic components and equipment. The software constituent is Arduino IDE, the exclusive development environment for Arduino. Users can write code for an Arduino board using the Arduino integrated development environment (IDE) and upload the program to the board via the USB interface on the control board. The board acts as a central hub, enabling independent control of various electronic devices. This system is the smallest available to ensure the reliable operation of multiple peripherals.

3.1.1 Arduino UNO R3 Development Board

Arduino UNO R3 is a common Arduino series main control board, equipped with the ATmega328P chip and has 14 digital IO ports and 6 analog IO ports. It only needs to be connected to the computer through a USB data cable for power supply, program downloading, and data communication. Pins support reuse, greatly enriching the possibility of carrying more peripheral devices and optimizing the efficiency of multi-thread processing.

In this Design, the Arduino UNO R3 Main Control Board is Selected for the Following Reasons:

1. UNO R3 is used by a large number of users. After years of development, it has formed a complete user ecosystem with many practical library functions and routines.
2. UNO R3 can provide more IO interfaces, and can avoid redundant IO ports while successfully realizing specified functions.
3. It has an IDE (program development environment) with good readability, which is flexible, convenient and easy to use.

3.1.2 Arduino IDE

A highly stable intelligent inspection vehicle system is inseparable from software-level design. The design of the program is equivalent to giving the intelligent inspection vehicle system the ability to think and maneuver, allowing the functional modules to function, and is an indispensable and important part of the overall design. The controller used in this design is Arduino UNO R3, which uses the ATmega328 control chip. The underlying language is based on the C/C++ language and does not require users to have an in-depth understanding of how its core operates. Arduino IDE (Integrated Development Environment) is a free and open-source electronic platform. Arduino's own development tools are mainly used for writing and developing Arduino programs. Arduino is essentially a microcontroller development board. Using IDE (Integrated Development Environment) for programming will greatly expand the practical application scenarios of Arduino. By writing programs on the IDE, we can interact with various sensors, control other components, and implement communication functions with other devices.

3.2 Main Program Design

The intelligent inspection vehicle's system program follows modular programming concepts by encompassing the motor drive, initial configuration, wireless remote control, and other programs. These programs only require calling during the programming process, leading to efficient problem-solving during the test process.[7]

The main program follows the process shown in figure 5. Firstly, the Arduino controller is initialized along with each

individual pin, following which the sensor sends a signal to detect potential obstructions. If no obstacles are present, the intelligent detection vehicle travels directly until it reaches its destination. However, if an obstacle is detected, the vehicle body moves according to both the algorithm and the inspector's instructions. Upon detecting defects, damage, or danger in the pipeline, the relevant data on the road section and location are automatically recorded and transmitted in real-time via the information transmission module.

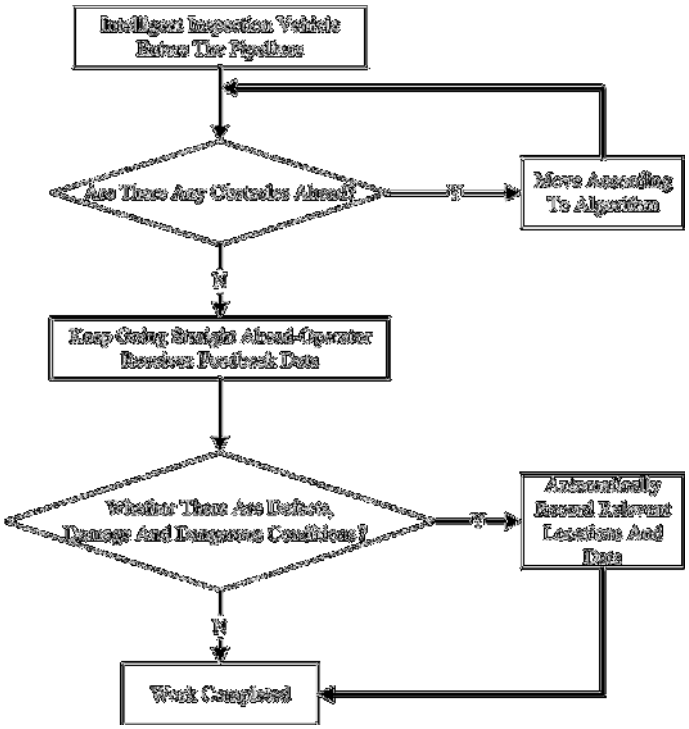


Figure 5: Main Program Design Diagram.

4. CONCLUSIONS

This article designs an intelligent inspection vehicle based on the Arduino platform, equipped with functions through modular design. The robot's motion actuator consists of a power supply and four DC reduction motors and uses Mecanum wheels as the driving wheels, which can realize a variety of motion modes such as translation, tilting, and rotation of the mobile robot. The inspection vehicle can meet the requirements for drainage pipeline inspection, can improve the safety, environmental protection, and work efficiency of drainage pipeline inspection work, and has certain practical value.

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REFERENCES

1. *2022 Urban and Rural Construction Statistical Yearbook. (2023, October 13). Ministry of Housing and Urban-Rural Development of the People’s Republic of China.*

https://www.mohurd.gov.cn/gongkai/fdzdgknr/sjfb/tjxx/index.html

2. *Yang M. (2023). Research progress on urban drainage pipeline inspection robots. Guangdong Building Materials (08), 132-134.*
3. *Wang J., Deng Y., Li Y. & Zhang X.(2020). Review of drainage pipeline detection and defect identification technology. Science, Technology and Engineering (33), 13520-13528.*
4. *Analysis on the Principle of Infrared Thermal Imaging Non-Destructive Testing Technology. (2018, November 13). SOHU.Com.* https://www.sohu.com/a/275065068_100130443
5. *Du Y., Xu C., Ma Y. & Zhao S. (2021). Oil and gas pipeline inspection robot prototype design and simulation analysis. Mechanical Design and Manufacturing (03), 194-197. doi:10.19356/j.cnki.1001-3997.2021. 03.044.*
6. *Xue L., Fang H. & Huang D. (2023). Design of Mecanum wheel intelligent vehicle based on Arduino. Equipment Manufacturing Technology (05), 43-45.*
7. *Huang C., Liu Y., He Y., Pan Y. & Kuang J. (2022). Design of omnidirectional mobile robot based on STM32. Information Recording Materials (09), 210-213. doi:10.16009/j.cnki.cn13-1295 /tq.2022.09.036.*
8. *Y K. H. Li, J. S. Chen, and Y. M. Zhang in their research "Double-Electrode GMAW Process and Control" Toyota Motor Manufacturing North America, Inc.*
9. *Dingjian Ye, Xueming Hua, and Yixiong Wu Research Article mention "Arc Interference Behavior during Twin Wire Gas Metal ArcWelding Process" (2013).*
10. *Robert Bogue/Industrial Robot The international journal of industrial and service robotics/Emerald Publishing Limited 06/10/2019.*
11. *Peiquan Xu & Guoxiang Xu & Xinhua Tang & Shun Yao, "A visual seam tracking system for robotic arc welding", (2019).*
12. *Deborah Santos, Thiago Silva Geraldi, Leonel Dimas de, "Cold Wire Addition in MAG Welding", (2018).*
13. *Juho Jouttijärvi, Melvin Vimal Raj, "Semi-automatic robot welding", (2018).*