Design of a cleaning robot for the interior of a mobile pressure vessel

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Abstract. Mobile pressure vessel in operation, will produce a lot of impurities inside the container. Up to tens of kilograms to hundreds of kilograms. The impurities are not only flammable and explosive, but also toxic and harmful. Moreover, the internal structure of the container is complicated, and it is difficult to remove it with conventional water cleaning or steam purging. which will cause explosions, personnel poisoning and other hazards during welding and inspection. In this article, for the inspection and cleaning of mobile pressure vessels, how to design a semi-automatic robot to remove impurities inside the container and ensure the safety of the inside of the container, The authors published their own design ideas.

1. statement of problem

1.1 The question
Mobile pressure vessels that carry dangerous chemicals such as liquefied petroleum gas, industrial cracked carbon five, butadiene, etc., due to the quality and characteristics of the medium, will form silt-like and powdery impurities inside the container. Since impurities mostly gathered in the middle and rear of the container, due to structural reasons, it cannot be removed by conventional washing methods, and can only be manually removed by personnel entering the container. Since impurities will continue to volatilize toxic, harmful, flammable and explosive gases, it is a huge safety hazard for personnel entering the container. Therefore, it is very important to remove internal impurities before personnel entering the container.
1.2 Situation Analysis
Due to the complicated internal structure of mobile pressure vessels, there is no robot that can completely remove impurities inside mobile pressure vessels in China. For example, the cleaning robot cooperated by Hei Longjiang Bayi Agricultural University and Hei Longjiang Agricultural Machinery Engineering Science Research Institute is based on path planning algorithms to strengthen the function of avoiding obstacles. The cleaning robot cooperated by Guangdong Normal University of Technology and Guangzhou Maritime University, through the multi-path planning control algorithm, enables the robot to complete the whole area coverage walking. Foreign research on the application of cleaning robots is very extensive. In addition to high-rise building cleaning robots and planar cleaning robots, there are also cleaning robots in complex environments such as underwater, water surface, irregular planes, and elastic objects. To sum up, the more mature cleaning robots are only suitable for specific occasions or have limitations. In order for the robot to realize the removal of impurities in the mobile pressure vessel, it must meet many conditions at the same time, such as obstacles, cleaning ability, explosion-proof level, gas detection function, etc.

2. The main content of the research

2.1 Robot cleaning method
According to research, when cleaning up impurities, a large amount of toxic, harmful, flammable and explosive gas will be released quickly, and personnel may be poisoned or suffocated within a few minutes, or a deflagration accident may occur. Part of the medium will form powdery impurities inside the container, or mix with iron oxide into agglomerated garbage, which will accumulate at the bottom of the container and more at the end of the container. Therefore, the robot only cleans the impurities at the bottom of the container to eliminate potential safety hazards. The robot uses a 24 volt DC power supply as the driving energy source, and is designed as a six-wheel drive. The internal image is captured by a panoramic camera, and then the robot is controlled by an external touch screen to make the robot move forward over obstacles at the bottom of the container. The sucker at the end can adjust the angle up and down, and adopt the negative pressure absorption method to recover the impurities to the external special recycling bucket.

2.2 Visualization research
The robot is equipped with a 360° panoramic explosion-proof camera with its own light source and 2 million-5 million high-definition pixels; the front and rear dual cameras can observe the inside of the container in all directions. The camera data is directly connected to the external control screen, which is convenient for external personnel to control the robot operation, and to monitor the internal situation of the container in real time, and save relevant inspection images and screenshots.

Fig.1. The main components
2.3 Ability to overcome obstacles
Generally, the obstacle inside the container is a reinforced plate with a height of about 100-130mm and a thickness of 6-10mm. The structure and size of the reinforced plate are unique to mobile pressure vessels, normal crawler type and ordinary four-wheel drive are difficult to cross smoothly. The solution is to use six-wheel drive. The front four wheels are of balance wheel structure. The diameter of each drive wheel is designed to be between 160-200mm. There is enough power and grip to ensure smooth crossing of obstacles with a height of 150mm. The driving wheel is made of a special wear-resistant rubber mold, which has a long service life, adapts to various chemical corrosion, and has explosion-proof and waterproof functions. It tries to reduce the center of gravity of the frame, widen the drive wheels to increase the grip, and increase the weight of the drive wheels if necessary to improve the overall stability. It should be ensured that there is no tipping and slipping when traveling on a 60° slope. On this basis, it minimizes the frontal width of the frame to adapt to a narrower space. In the case of satisfying stability, it considers designing a frame with adjustable width.

2.4 Gas detection function
The robot is equipped with a professional gas detection device, which has an IP66 protection level. Considering the overall compact design, the gas detector retains only the important detection function components to be mounted on the robot, and the detection data obtained is fed back to the external control terminal screen through multiple high-sensitivity gas sensors. It has the function of detecting the concentration of oxygen, chlorine, carbon monoxide, flammable and explosive gases at the same time, monitoring the change of gas concentration in real time throughout the process, and when the gas concentration reaches a certain critical value, it will trigger an alarm device to feed back to the external control terminal screen.
2.5 Body design
Considering the small import of the container, the size of the robot should also be designed to be small and flexible, which should meet the requirements of the entrance with a diameter of 450mm. Due to the special structure inside the container, the size of the robot needs to be strictly controlled. The length, width and height should be controlled within 590mm×360mm×315mm. The overall frame is made of aluminum alloy to reduce weight. The total weight is controlled within 30 kg. It should be able to ensure that the robot can turn flexibly inside the pressure vessel, and the parts of the robot should be as compact and smooth as possible to avoid hooking and jamming.

Fig. 4. Body design

2.6 Recycling system
The suction cup recycles impurities to a special recycling bucket through a vacuum hose. Since the length of the suction hose exceeds 10 meters, this will weaken the suction force of the suction cup, so the motor of the recovery system must ensure a certain power. Therefore, the motor of the recovery system must ensure a certain power. The motor power is designed to be about 7.5 kilowatts to ensure that it can absorb impurities. The recovery system has the functions of overall airtightness, elimination of static electricity and explosion-proof.

Fig. 5. Dedicated recovery device

2.7 Integrated module and PLC control system
Adopting brand PLC controller, after program debugging is completed, writing its program into PLC memory through programmer, the input cable and the vacuum hose are tied together and connected to the robot through a semi-automatic pipeline transport box, connecting the signal inside the container to the control actuator through the input module to control the robot to complete functions such as walking, vacuuming and monitoring.

3. Concluding remarks
As the country's demands for clean energy continues to increase, the number of petrochemical companies and mobile pressure vessels is also showing an upward trend. In the process of cleaning and inspection of mobile pressure vessels, traditional manual operations have huge safety risks, low efficiency and high costs, and accidents of casualties often occur. Robots replace manual operations, with high work efficiency and safety factor, and cost savings. While improving overall economic
benefits, it also reduces personnel safety risks and avoids the social impact of accidents. In addition, it can also change the problem of "difficult to clean up impurities" of mobile pressure vessels. At the same time, it also fills the gap of the mobile pressure vessel cleaning robot.

References

[1] 이승희 et al. Development of Mobile Robot for CAS inspection of Oil Tanker[J]. The Journal of Korea Robotics Society, 2007, 2(2) : 161-167.
[2] (2021). Request for Extension and Revision of a Currently Approved Information Collection: Annual Tank Car Survey. The Federal Register / FIND, 86(006), pp. 2030-.
[3] GUTZEIT G. (1949). Treatment of complex chemical wastes resulting from tank car cleaning operations.. Sewage works journal, 21(1), pp. 91-99.
[4] G. Gutzeit. (1949). Treatment of Complex Chemical Wastes Resulting from Tank Car Cleaning Operations. Sewage Works Journal, 21(1), pp. 91-99.
[5] Jae-Hoon Kim and Byung-Chun Goo. (2008). A Study for the Safety Regulation of Tank Car for the Hazardous Material - General Oil Tank Car. FIRE SCIENCE AND ENGINEERING, 22(4), pp. 70-75.
[6] Xing Xiquan, Zhu Haiqing, Zhang Chunbo, Zhang Xiong. LPGStudy on the Mechanical Characteristics of the Wall-climbing Jet Cleaning Car[J]. mechanical strength, 2020, 42(03):758-762.