

# Automation Solution to Wall-climbing Robot Working for Large-scale Metal Spherical Tanks

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**Abstract.** The modern weld inspection by robot operation has been attractive for safe-guarding large-scale pressure equipment in chemical energy industry by avoiding hard labors in harmful and toxic environments, with lower costs and higher efficiency and especially without the need of complex scaffolding. A wall-climbing robot based on permanent magnet adsorption is introduced to perform weld inspections of large-scales metal spherical tanks. This paper expounds the mechanical structure, intelligent visual functionality and intelligent walking system of the designed robot. Its optimized walk paths are proposed. Numerous engineering tests indicate good performance of designed robot in achieving high-quality surface treatment and non-destructive testing for large-scales metal spherical tanks. The suggested scheme provides an automation solution to wall-climbing robots working for large-scale metal spherical tanks.

**Keywords:** robotics, automation, welding.

## 1. Introduction

Large-scale metal spherical tanks are important production devices in the chemical energy industry, storing high-temperature and high-pressure toxic industrial materials. They are widely used and more than hundreds of bulidings in China's developed provinces. Weld defects such as corrosion, cracks, holes, etc. be prone to induce structural integrity failure of spherical tanks, even to cause catastrophic loss and human death[1]. In order to guard the safety of spherical tank during the long-term operation, the special equipment safety law makes the requirements of regular annual inspection. Weld inspection for the spliced steel plate of spherical tank has been widely carried out.

Wall-climbing robot operation replacing manual inspection is innovative and distinctive. In such a way, there is no hidden danger of harsh and toxic environments, no need of scaffolding, and lower costs and higher efficiency. However, there are two difficulties to research and develop intelligent inspection robots. On one hand, the design of automatic inspection device based on the existing principles and devices widely used in manual inspections is a technically hard work, that no longer relies on rich personal technical experiences[2-3]. The following is the second tricky puzzle. Unlike on supported ground, wall-climbing robot cannot hang and walk naturally on the curved surface of metal spherical tanks, as if gravity is not present. Appropriate physical measures are needed to take to ensure robot reliably attached to and safely walk on spherical tank curved surface[4-5]. Robot falls is a serious situation, destructive to its own body, dangerous to the on-site personnel. Fall accident may also cause serious damage to the operated tank, that will bring huge economic losses and delay production on schedule. Therefore, it is necessary that robot walks safely and reliably and no fall even in the event of an unexpected power failure. In addition, the driven robot is also anticipated with flexible, convenient and intelligent mechanical actions.

Many previous literatures have expounded some different technical solutions to related wall-climbing robots[6-8]. Quite commendable and valuable, but those researches are deficient in the automatic behavior researches of robot's response action. This work introduces an innovative and distinctive automation solution to wall-climbing robots working for large-scale metal spherical tank,

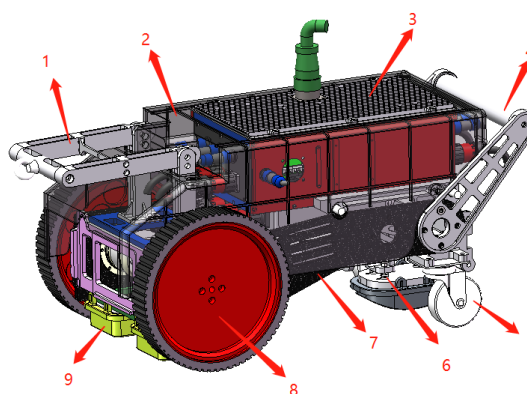
including mechanical structure, intelligent visual ability, intelligent walking system and walk path considerations.

## 2. Mechanical and Functional Designs

Large-scale metal spherical tanks in the chemical energy industry are assembled from spliced steel plates with a certain curvature by double side welding of these plates, as shown in Figure 1. Wall-climbing robot with the mounted inspection devices is designed to walk on the inner curved surface of spherical tanks and to perform weld inspections in the current work. The designed robot is mainly composed of mechanical body, physical adsorption device, drive system, weld inspection system and intelligent control system, as shown in Figure 2. Some basic structures are also marked in Figure 2: 1-Multifunctional lifting handle; 2-Outer frame; 3-Electric circuit box; 4-Multifunctional rear handle; 5-Universal wheel; 6-Magnetic buffer device; 7-Body bracket; 8-Drive rubber wheel; 9- Magnetic adsorption unit.



**Figure 1.** Metal spherical tanks in the chemical energy industry



**Figure 2.** Basic structures of the designed robot

Steel plates of spherical tanks are ferromagnetic metal. Complex magnetic bridge arrays of strong and permanent magnet materials have been explored to provide the reliable physical adsorption force for wall-climbing robots. Under the dual-motor differential drive, the designed robot flexibly walks on curved surface at various adjustable speeds of 0-3.4m/min and ranges from 0-360° in-situ steering. The inspection device mechanism is driven adaptively on curved surface by an algorithm-controlled electric putter. The distance between inspection device and the operated curved surface is adjusted to maintain as a suitable value in real time. That undertakes the robot's operations in the target weld area always are effective and not in vain.

In the remote control mode based on a ground console, the designed robot integrates mechanical structure, intelligent control and sensing technology. With the assistance of intelligent vision system, the remote console placed in the healthy operating environment outside spherical tanks is conducted to command the robot's response action. High-definition camera images and various parameters such as running mileage are returned and recorded by a dispatching management software based on the Windows computer system. Real-time and accurate data is communicated through CAN (Controller Area Network), and the communication rate can reach 1Mbps because communication distance is less than 40M.

Powered by cables, the designed robot can continuously walk and operate on spherical tanks for a long time for dozens of hours. Before running, the robot should be connected to the fall arrester device installed on site tank top by hooking one end of the safety rope of the fall arrester to the robot's multifunctional lifting handle. Even in an accident, the robot will be pulled by the safety rope and not fall to the bottom of the tank to cause security incident or huge losses. Consequently, the operation safety of the robot in the whole inspection process is better guaranteed.

### 3. Visualized Smart Vision

High-definition and wide-angle digital cameras are mounted on the anterior, caudal, and ventral positions of the designed robot to take image information in these three areas, which helps the operators to remotely monitor operating environment in real time. These cameras have the functions of capturing, recording and storing images, which provides the original analysis data onto image recognition processing and later inspection evaluation. In addition to these normal visual designs, a smart vision system set up an independent vision unit based on a PTZ (Pan/Tilt/Zoom) device is fixed on a tripod and placed in the bottom of the operated spherical tank, as shown in Figure 3.



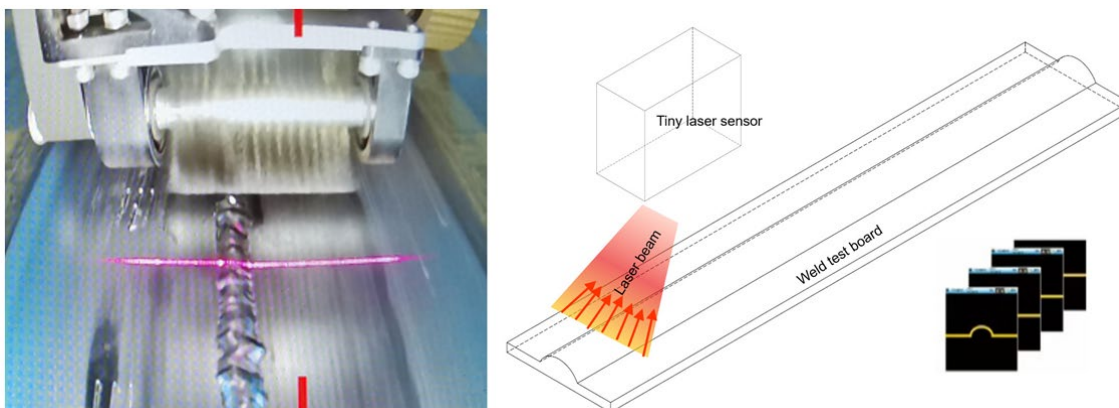
**Figure 3.** Vision unit based on a PTZ device

This independent vision unit has infrared night vision function. That can search and observe with 360° rotate motion in the horizontal direction and +90°~90° pitch motion. And it supports 3D positioning and zooming function. During zooming, the rotate speed is automatically adjusted according to zoom ratio of the lens with the horizontal speed from 0.1°~200°/s and the pitch speed from 0.1°~50°/s. By remotely performing this independent vision unit, the operators have a pair of eyes of monitoring the view field inside spherical tank, perfectly realizing the macroscopic panoramic observation of the robot's working positions and conditions.

### 4. Automated Smart Identifying and Tracking

Wall-climbing robot walks along longitudinal or annular weld routes on the curved spherical tank surface to perform surface treatment and non-destructive testing of weld inspections. Automated weld identifying and weld tracking are intelligent technical requirements for wall-climbing robot. The robot can automatically walk on the right route of current operated weld without human intervention that avoiding the operator to be having to hold the steering wheel all the time. That's a more efficient situation.

Weld heights of the spliced steel plates of spherical tanks are usually 2mm~5mm above the base metal. For identifying these welds, A high-precision aTiny laser sensor is utilized to high-speedly and stably measure height contour features on spliced steel plates as obtained cross-sectional shape. The sensor contains a high-speed laser beam transmitter and integrated intelligent processing software. As shown in Figure 4, Contour data is collected at the irradiated line of the laser beam. Numerous experiments have been conducted and compared with standard height contours of test boards, then the optimal mathematical algorithm of laser sensor processing was determined to accurately measure shape features of weld area. By real-time data analysing and processing, the robot will accurately identify the target weld based on height contour features of obtained cross-sectional shape.



**Figure 4.** Laser beam of a Tiny laser sensor and height contour measurement

For tracking these target welds on spliced steel plates automatically, some programs coded in the console are executed to correct the walking direction of the operated robot in real time based on the feedback how much the current target weld offsets the sensor laser beam of the robot. The designed robot usually operates forward at a well-behavior speed of 0.4m/s~0.6m/s. Once the maximum offset of weld tracking reaches 20mm, the operated robot is driven to turn left or right until the target weld is in the middle of the sensor laser beam.

The above-mentioned operational behaviors of the automated weld identifying and weld tracking reduce the work input of operators and significantly improve the quality and efficiency of inspection processings for wall-climbing robot. These are the highlight of the designed wall-climbing robot described in this article.

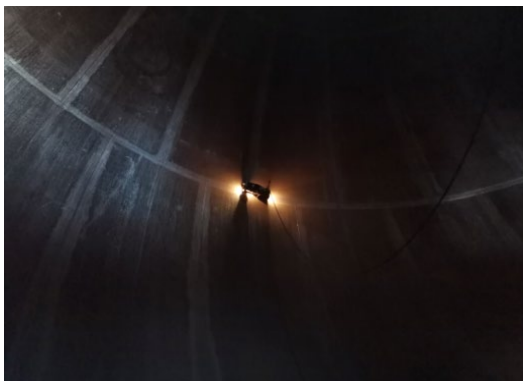
## 5. Engineering Application and Walk Path Optimization

As shown in Figure 5, the designed wall-climbing robot was applied to engineering tests of spherical tanks from many chemical companies. In these engineering practices, the surface treatment and non-destructive testing for weld inspections have achieved some good results. During the whole inspection process, the adsorption suspension of the robot has been verified as reliable and safe. Good maneuverability and intelligent behavior have also been confirmed. The weld area performed surface treatment of weld inspections is shown in Figure 6, with a high-quality metallic luster.

Welds of spliced steel plates of spherical tanks are parallel or intersectional rather than successive routes. It is necessary to discuss that what path the wall-climbing robot walks along to make weld inspections with better quality and efficiency. The robot carries out inspection operations when it walks in the weld inspection area with a slow speed about of 0.4m/s~0.6m/s, but walks with a fast speed until 3.4m/s during the process of arriving to the next target weld. The robot returns in time to the target weld position it leaves just now due to the consumable replacement and equipment maintenance with also a fast speed until 3.4m/s. Fast walking of the robot without weld inspection is unavoidable, futile and time-consuming. Reasonable work schemes and walk paths are needed to devise to save time and improve efficiency of weld inspection.

Figures 7 and 8 show the weld arrangement of a spherical tank with a volume of 5,000 cubic meters and the devised weld inspection scheme of two wall-climbing robots working together. The weld inspection area of two robots is divided by the left and right hemispheres of the operated spherical tank. Two fall arresters are installed in the manhole at the top of the spherical tank, and the cables of two robots are suspended. The walk paths are devised as follows: at the beginning of weld inspections, the No.1 and No.2 robots synchronously are driven to operate the girth weld in the divided upper hemispherical areas. Next, the object of the operations are the quadrilateral welds with two inner weld lines and adjacent Y-shaped welds on the top cover of spherical tank. Then, 24 longitudinal welds in the upper hemisphere are operated in sequence of the "down-up-down" S-shaped walk paths as shown in Figure 7 by indicated arrows. After equatorial weld operations are completed, the lower hemisphere

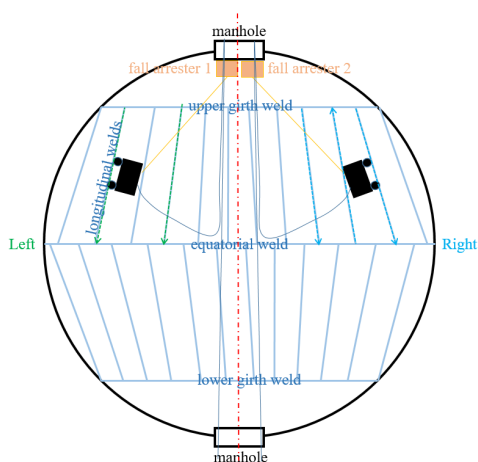
welds are operated by the same ways. According to data results, the weld inspections for the spherical tank of 5000 cubic meters take about 13 hours and 10 minutes in this situation of such two robots working together. This time loss is far less than that 7 days of manual inspection with five or six workers under complex scaffolding.



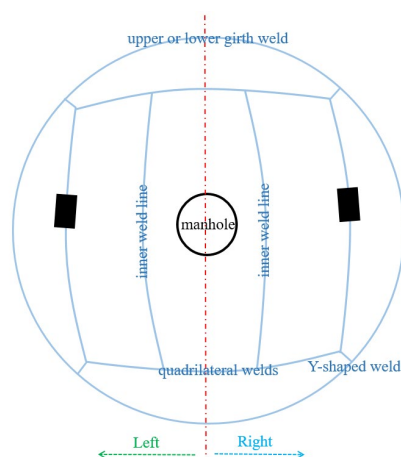
**Figure 5.** Wall-climbing robot working for spherical tank in engineering tests



**Figure 6.** Weld area after surface treatment of weld inspections



**Figure 7.** Weld arrangements of a 5,000 cubic meter spherical tank and "down-up-down" S-shaped walk paths



**Figure 8.** Quadrilateral welds with two inner weld lines and adjacent Y-shaped welds on two covers of spherical tank

## 6. Conclusions

The modern weld inspection by robot operation has been attractive for safe-guarding large-scale pressure equipments in chemical energy industry. Wall-climbing robots mounted inspection devices have a very good prospect of engineering application. A wall-climbing robot based on permanent magnet adsorption is introduced to perform weld inspections of large-scales metal spherical tanks. The intelligent dispatching management software based on the windows computer system, visualized smart vision and automated smart identifying and tracking together make up a comprehensive intelligent control system of the designed robot. Numerous engineering tests indicate good performance of maneuverability and intelligent behavior of designed robot in achieving high-quality surface treatment and non-destructive testing for large-scale metal spherical tanks. The suggested scheme provides an automation solution to wall-climbing robot working for large-scale metal spherical tanks.

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