

Conceptual Design of a GRC Robot as the New Generation of Guardrail Cleaners

A.R Rajabnejad^{1,*}, H. Shahidian², Sh. Niknejad³, H. Maleki⁴, S.R. Farsangi¹

¹Center of Excellence in Design, Robotics and Automation, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran.

²Mechanical Engineering Department, University of Melbourne, Melbourne, Australia

³School of Mechanical Engineering, Kashan University, Kashan, Iran

⁴Pharmaceutical Sciences Branch, Azad University, Tehran, Iran

Article Info

Article history:

Received 25 January 2016

Received in revised form

20 February 2016

Accepted 28 February 2016

Available online 15 March 2016

Keywords

GRC, guardrail, robotics, Automation

Abstract

Preservation of the beauty of a city has proven to be an effective approach to improving the tourism industry, living safety and economic growth[1]. Since public transportation vehicles such as trams, buses and trains are highly visible to the residents of a city and tourists; their cleanliness has a large impact on its visual appeal. Guardrails, being in easy view of passengers, should look tidy and orderly. Although guardrail maintenance is generally performed by laborers, it would be of great benefit to mechanize this task. This study therefore sets out to develop the conceptual design of a novel automatic system called Guardrail Robot Cleaner (GRC) for this task. The system design is presented from mechanical and electrical points of view. Conclusively, the application of robotics to such services could be beneficial to some extent and increase public satisfaction.

1. Introduction

GUARDRAILS are protective devices for redirecting errant vehicles from a dangerous path. The term “guardrail” refers to the longitudinal barriers normally installed along the side of the road to prevent a vehicle from colliding with an obstruction or taking a perilous, off-roadway course where recovery of vehicle control is not reasonably possible. Moreover, guardrails are designed to keep bus lanes away from other vehicles routes. Generally, municipalities are responsible for the cleanliness of guardrails, so many facilities and workforces are employed to support guardrail maintenance.

For many years this process has been done with many human laborers and very simple tools such as a bucket of water, soap, and a sponge. Although traditional methods have been quite well developed over time, there are some notable problems regarding these methods. Previously, the manual guardrail cleaning procedure consisted of three different parts: presoaking, foam spraying and final washing. Since this process is so labor intensive, this method is becoming less common in favor of semi-automated guardrail cleaning trucks that have entered the market. The main benefits of the new approach are the reduction of the required human labor and time needed to perform cleaning. To this end, a truck that carries a tank of water and a tank of washing liquid goes along the guardrail and performs the various cleaning steps. Firstly, water is sprayed onto guardrail through the nozzle of a long hose

which is attached to the container. Later on, this process is repeated with washing liquid and it is sprayed all over the guardrail. Finally, brooms are brushed over the guardrail by laborers, and the detergent is rinsed off. Figure 1 illustrates this procedure.

This laborious procedure has been followed in many countries for the last three decades; however, it has a lot of demerits. In spite of some improvements stemming from automation and specialized equipment, it is still time consuming. Further, the need to move slowly and frequently, stop along the highway makes heavy traffic, since it makes the road narrower. Besides, from an economic point of view, it is not beneficial for the municipality to follow this method; In fact, a great deal of money should be paid for cleaners’ and truck drivers’ salaries, detergent and fuel. Moreover, due to leakage of water and detergent throughout the washing task, the highway will be made dirty and full of soapsuds and this leads to more expenses for the municipality to pay for the above mentioned drawbacks of the previous approaches gave rise to the adoption of another method. The new method of guardrail cleaning is more economic and less manual. In this method, a set of brushes and nozzles mounted on the front of the truck by some pipes do the cleaning process, as depicted in Figure 2.

The water and detergent are pumped from different containers and go through pipes to nozzles to be sprayed at high pressure onto the guardrail. At the end of the process, brushes rotate over the surface of the guardrail to remove spots. All parts of the procedure are controlled by a single truck driver. In terms of benefit, removal of the need for laborers and the performance benefits arising from bigger

Corresponding Author,

E-mail address: Rajabnejad@alum.sharif.edu

Phone No: +82 10 9628-7654

All rights reserved: <http://www.ijari.org>

brushes and a bigger reservoir are notable. However, this method has the same disadvantages as the previous method, such as contributing to traffic accidents and causing traffic congestion.



Fig.1. Traditional method of guardrail cleaning[2]



Fig.2. Usage of trucks and big brushes to wash guardrails[3]

Making use of robotics to automate cleaning process has always received a lot of attention [4-6]. Unfortunately, in terms of guardrail cleaning, there is only one study by Oomura in 1997 who invented a semi-automatic guardrail cleaner which clamps on a guardrail and perform two tasks: cleaning and painting[7]. However, this motorized vehicle also cannot be considered as an appropriate cleaner, since it just removes dust and doesn't use water and detergent.

To address these issues while retaining the benefits of the semi-automated guardrail cleaning trucks, in this study, we present the conceptual design of a novel automated guardrail cleaning mechanism. It should be noted that the following design is based on a patent registered by the author[8].

2. Overall Design

In the previous section it was argued that guardrail cleaning is a needlessly laborious manual process that could benefit from automation. In this section the conceptual design of the GRC robot, designed to automate the guardrail cleaning process is developed in detail.

2.1 Washing Chambers

In order of importance, the design of the washing chambers comes first. There are two main chambers consisting of four vertical brushes, which form four parallel pairs. The

resulting configuration can wash both sides, simultaneously. The upper head of each brush's shaft ends in a pulley that attaches the shaft to the motor. A fluid ball bearing holds the lower part of the shaft to tolerate high rotational velocity of brushes. Each pair of brushes is equipped with a motor that utilizes a belt and pulley system for power transmission. The driven pulleys are of common diameter, and in order to achieve a higher shaft rotational velocity, they are smaller than the driver ones. A V-belt is the most proper choice for increasing the amount of transmitted torque. The cover of the washing chamber is made of aluminum plate since it is light and can be molded as desired. Of course, the shape of the cover is really noteworthy, as it should properly interface with the guardrail; so, it is a better choice for it to be a bit wider than the guardrail's thickness and brushes operational circle.

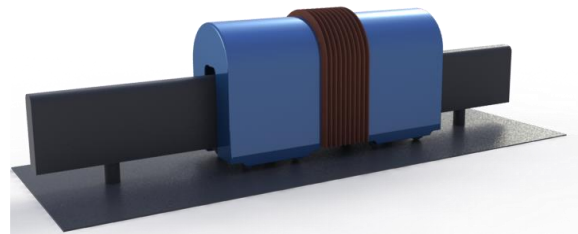


Fig.3. GRC robot concept

In general, guardrails are mounted on posts which are drilled into the ground, and these hurdles make some difficulties for the robot's movement; hence, each chamber is equipped with four wheels which have two motors to be run. In this way, the robot can move more smoothly with less possibility of being tripped up on obstacles. Furthermore, as chambers should move along guardrails, and in some places they should turn left or right, they are attached via an articulation joint resembling an articulated bus attachment to ease their movement.

Respecting the roof of the camber, a hemi-cylinder is considered, because it provides greater space over the brushes for putting motors, power transmission systems and resources. The internal lower part of the chamber has a slant shape for collecting leaked dirty water which also plays the role of a dirty water reservoir. Component specifications of the transfer table are given in Table 1. All parts named in Table 1 are also shown in Figure 4.

2.2 Resources

In the next stage, the reservoirs' design plays the predominant role. As mentioned in the previous section, resources are placed in the hemispheric part of the robot. The main reason behind this idea is making use of gravity, instead of extra pump, to input fluid from reservoirs. Actually, in this novel mechanism, there are three different fluids that are sprayed onto the surface of guardrails: clean water, detergent and dirty water; so we need three resources. Clean water and detergent are stored in a container with two separate enclosed spaces; one of them stores water and the other one carries detergent. The water chamber is located behind and the detergent chamber in the forward section. Additionally, the dirty water reservoir, which is located at the lower part of the washing chamber,

is fed by the leakage of water and detergent in the previous stages of washing.

In each chamber, two pumps are considered to return the dirty water to the washing process. These pumps are situated in the internal area of the washing chamber and in the gap between the sets of brushes; one in the right side and one in the left side of each container.

The outlets of the pumps are attached to small vertical pipes, which are equipped with nozzles. These nozzles can be at the same level as the middle part of the guardrail. The detergent container and water container should be fed manually by removing the hemispheric roof. For this, fire hydrants, which are located at intersections in most cities, can be used to feed the clean water chamber. This manual process could be remarkably important, owing to the fact that water is a limited resource and the GRC could lead to energy, water, and money savings. In addition, the water and detergent reservoirs are supplied via four controllable valves which can be switched on or off.

Valves are placed in the floor area of the hemisphere, in the middle part of each half of the reservoir, with respect to the midline of the robot. Each valve is equipped with a nozzle to spray fluid onto both sides of guardrail. The angle between the nozzles' heads and the horizon should be ranged between 20 and 50° to cover all surfaces on each side of guardrail.

The dirty water chamber of a container has two valves which are located over the chamber close to the medial edge. These valves increase the efficiency of the system by reduction of fluid loss. Table 2 demonstrates the reservoirs parts and its specifications. All components named in Table 2 are also shown in Figure 5.

2.3 Movement Mechanism

The movement mechanism is explained in the following section. Since the GRC includes two similar containers which are interconnected, there is a similar design for both of them. In order to facilitate movement of containers and ensure maximum stability, a four-wheel design is considered for each container. There are four identical motors to drive wheels which are located close to each wheel.

3. Operating cycle

The process starts with turning all motors on. Following that, four brushes start to rotate, the detergent supply valves in the leading part of the robot are opened, and detergent begins to soak the target guardrail through nozzles. Then, the detergent container valves are shut, the water reservoir's valves are simultaneously opened, and water begins to flow onto the guardrail. The system consists of two similar units, one in the front and one in the back, performing the same operation. The washing process results in leaked dirty water, and this dirty water is recovered to be used by both bodies. Once the recovered water tanks have been filled, both water reservoirs' valves are closed, and the washing process begins using dirty water instead of clean water; to do this, the dirty water chambers' valves for the leading container are opened and the procedure continues. Once the dirty water reservoirs are empty, the GRC begins using clean water again. The whole operating process is illustrated in Figure 6 and in flow chart

form in Figure 7.

4. Control and electrical units

4.1 Electrical Units

The electronic module of the GRC robot is designed as follows. Firstly, in order to run each body's brushes' motors, two big lithium batteries which are situated in the middle part of the structure and attached to the internal surface of the articulation joint, parallel to the guardrail and away from liquid leakage, are considered. This is shown in Figure 8(b). The main reason for such a design is to avoid soaking the batteries, which could cause damage to the electrical components. In the lower part of the robot, wheels' motors are supplied by four batteries, which are located close to the wheels and motors. This consideration provides the robot with a four-wheel drive mechanism to facilitate its movement in different situations. It should be noted that making use of one motor per two wheels is also good to consider, but in this study, it is preferable to make a design with as few limitations as possible. In order to run the dirty water pumps, a motor with a battery that is placed in the space between the articulation joint floor and the big batteries is adopted; so, there are four batteries for all four pumps in both bodies. Table 3 describes those mentioned parts and their features and Figure 8 depicts them.

4.2 Sensors

This section will discuss which sensors are required for the robot to successfully perform guardrail cleaning. Broadly speaking, some sensors and switches should be taken into account to provide proper monitoring and control of the whole system for failure avoidance. For this purpose, two optical sensors are positioned in the front and rear part of the GRC to monitor the route and provide the required information regarding any barrier, ending of the guardrail or change in orientation. All chambers are equipped with one liquid level detector, but its application is different in each chamber. In the detergent chamber, this sensor just reports when the chamber will need to be refilled. In the clean water chamber, in addition to showing the refilling time, it also is used to determine the appropriate time for opening and closing of the chambers' valves. The latter role is performed by the same sensor in dirty water chamber also.

4.3 Control

The GRC robot is controlled by central control unit. In normal conditions, the control unit maintains a uniform traveling speed and watches the amount of water and detergent in each reservoir. Once an obstacle is sensed through an optical sensor placed in front of the GRC robot, the control unit stops the GRC robot through controlling the wheel motors. If the clean water reservoir becomes empty, then the control unit closes the clean water valves and opens the dirty water valves instead. The system can also be operated manually via wireless communication with the control station

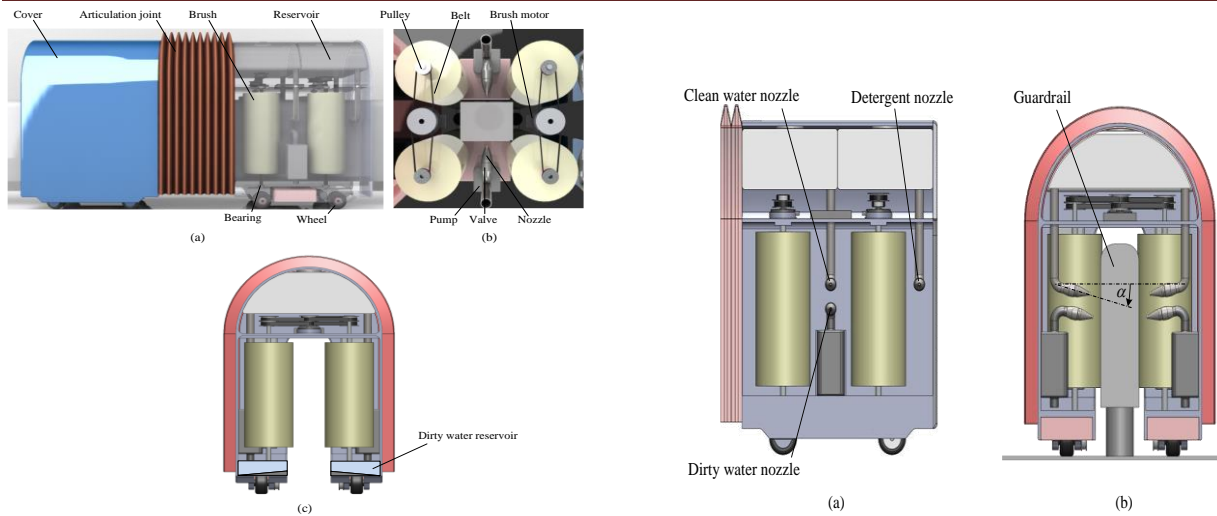


Fig. 4. Washing Chamber (a) side view (b) top view (c) front view Fig. 5. Nozzles (a) position of nozzles (b) angle of nozzles.

TABLE 1. Washing Chambers Specifications

Item No.	Item Title	Item Diameter (cm)	Item Width (cm)	Item Height (cm)	Item Thickness (cm)	Item Material
1	Cover & Structure	n/a	140	90	60	Aluminum
2	Brushes	0.75 (Bar Diameter)	20	60	20	Nylon
3	Pulleys	5	n/a	n/a	2	Stainless Steel
4	Motors	DC Brushless Gear Head (24 Volts, 200 Watts, 150 Rpm)				
5	Belts	6	1	n/a	0.3	Rubber
6	Ball Bearings	0.8 (inner) 1.1 (outer)	0.7	n/a	n/a	Ceramic, Chrome
7	Wheels	8	5	n/a	n/a	Stainless Steel
8	Articulation Joint	n/a	30	95	65	Rubber

TABLE 2. RESOURCES SPECIFICATIONS

Item No.	Item Title	Type	Item Diameter (cm)	Item Width (cm)	Item Height (cm)	Item Thickness (cm)	Item Material
1	Reservoirs	n/a	n/a	45	15	1	UPVC
2	Pumps	Centrifugal	1450 Rpm, 230 M3/hour Discharge flow capacity				
3	Valves	Single Port	4	n/a	3	0.2	Stainless Steel
4	Nozzles	Full cone	Inlet:3.6 Outlet:1 Orifice:1.9	n/a	5	n/a	Stainless Steel

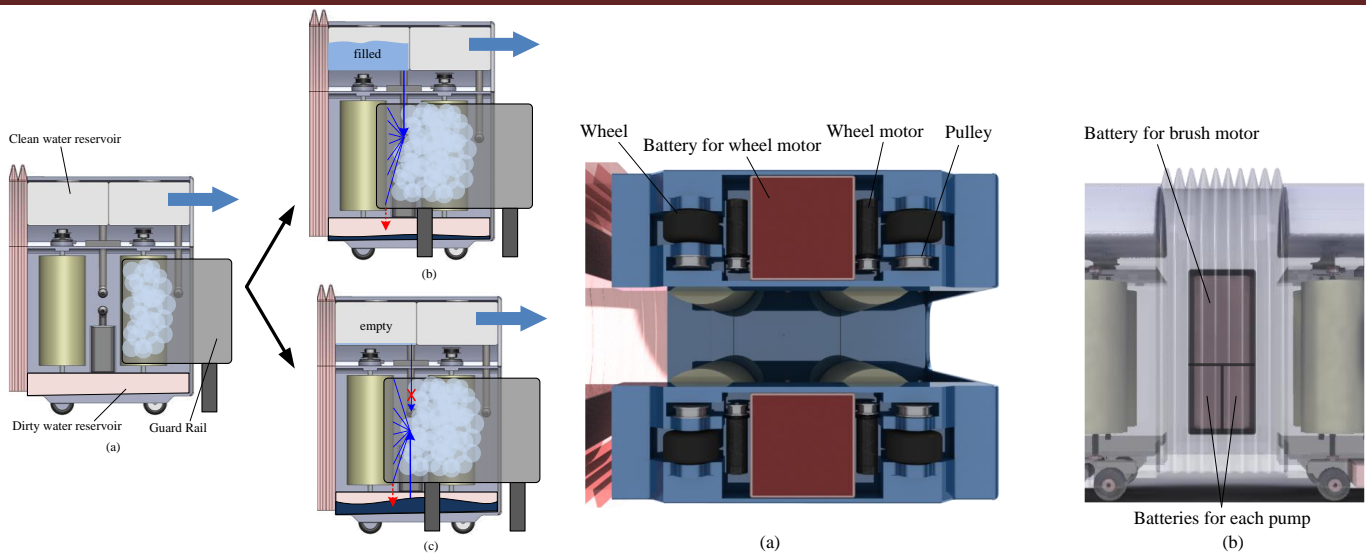


Fig.6 Operating process: (a) Soaking
 (b) Washing with clean water when the clean water reservoir is filled
 (c) Washing with dirty water when the clean water reservoir is empty.

Fig. 8.GRC robot: (a) bottom view, and (b) Inside of articulation joint.

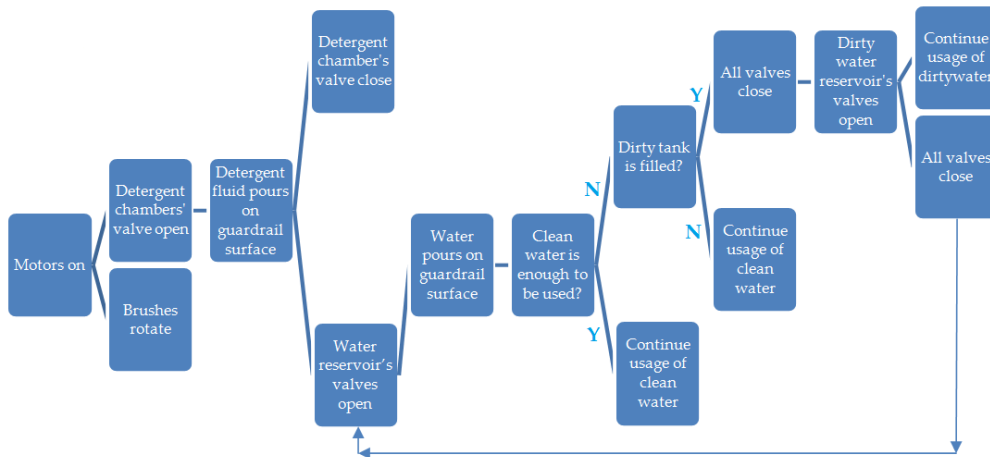


Fig. 7. Flow chart of the operating cycle

TABLE 3.CONTROLLING AND MOVEMENT MECHANISM SPECIFICATIONS

Item No.	Item Title	Type	Item Diameter (cm)	Item Width (cm)	Item Height (cm)	Item Thickness (cm)	
1	Motors	DC Brushless Gear Head (24 Volts, 200 Watts, 150 Rpm)					
2	Optical Sensors	Ultrasonic Distance Sensor (#28015)	4.3	1.6	1.8	Non metal	
4	Sensors	Liquid level detector	5	-	Probe length:2-3	Non metal	
5	Batteries	Car Battery	23	175	23	Non metal	

5. Conclusion

The purpose of the current study is to present a conceptual design of a novel guardrail cleaner robot. In comparison with conventional methods, the proposed approach has some advantages. One of the greatest merits of this robot is prevention of traffic obstruction in the street during guardrail cleaning. In fact, moving over the guardrail reduces the risk of highway blockage. In addition, reutilization of leaked fluids and the fluid recycling process presented in this study provide energy savings and reduce water loss. Further, the above mentioned design decreases the risk of accidents as a result of slippery roads by prevention of leakage and reuse of waste fluids. In terms of expense, as the requirement for human labor diminishes to two persons -one for refilling the reservoirs and one for maintenance - the developed robot is highly practical. From an environmental point of view, since there are no air pollutants which come out of the

GRC, it can be considered a green vehicle, which makes it more acceptable for use by municipalities and governments. Moreover, because the cleaning process is performed twice, first by the leading body and then by trailing one, the cleaning process is more thorough, and therefore the system is more effective overall. Finally, the total time needed for washing is shorter in the new approach, since there is no need for frequent stops, since the proposed system implements a continuous process. In conclusion, the new method shows another novel way that robotics can be applied to the automation of urban services. Although this study merely establishes the feasibility of the GRC system, in the near future, manufacturing of the GRC will be started and reported to pave the way for the further use of robotics in daily life.

References

- [1] Keep America Beautiful. 2001 Annual Review. 2001 [cited 2001; Available from: http://www.kab.org/site/DocServer/2001_annual_review.pdf?docID=121%20-%20205k.
- [2] HSE-MS Steering Committee of region 1 of Tehran Municipality. Guardrail Cleaning to improve citizen's welfare. 2014 [cited 2014; Available from: <http://www.safetehran1.com/Default.aspx?tabid=62&articleType=ArticleView&articleId=968>.
- [3] YIHONG Industrial Equipment Co. LTD. Freeway Guardrail Cleaning Truck YHQX-2.5B. 2014 [cited 2014; Available from: <Http://www.yhroadsweeper.com/products/guardrail-cleaning-truck/freeway-guardrail-cleaning-truck-yhqx-25b.html>.
- [4] Stelter, M., Fence cleaner. 2010, Google Patents.
- [5] Vogt, N.H., Cleaning apparatus for overhead rails. 1976, Google Patents.
- [6] Brunel, R., R. Fannon, and R. Legue, Overhead rail cleaner and oiler. 1974, Google Patents.
- [7] Oomura, Y., Guardrail cleaner. 1997, Google Patents.
- [8] Rajabnejad, A., Design of GRC Robot for Guardrail Cleaning, I.P. Office, Editor. 2010: Iran.