Autonomous Robot Arm Platform: Preliminary Report

Team Victory Lap

Suez Water Advanced Solutions/Utility Service Company, Inc.
JSaylor@UtilityService.com

Professor: Dr. Harvey Lipkin
ME 4182 - C
Erin Brennan
Alec Fenichel
Eric Hom
Josh Lieberman
Shaun Orr

The George W. Woodruff School of Mechanical Engineering
801 Ferst Drive
Georgia Institute of Technology
Atlanta, GA 30332-0405

Table of Contents

Executive Summary

Suez Advanced Water Solutions/Utility Service Company Inc. is a water systems company that provides water services to 7.5 million people in North America. In order to provide quality service, Suez maintains over 6,000 tanks by sandblasting and repainting over 100 water tanks per year. Suez aims to improve their current sandblasting process by utilizing an autonomous robot arm to clean the inside surface of the water tanks. The current design problem prohibiting Suez from employing the technology is a lack of a stable base for the robotic sand blasting arm. Utilizing the sandblasting arm within water tanks presents unique challenges when designing the base platform. First, the base needs to stabilize the arm when the sandblasting cycle is activated; movement of the base results in the arm's positioning system to fail. Second, the base must be able to move both horizontally along the base of the tank and vertically in order to sandblast the floor, wall and ceiling of the water tank. In addition to these requirements, the proposed solution must be easily assembled and disassembled in order to fit through the tank's thirty inch diameter entry hatch. After developing five possible conceptual designs, the initial selected design solution is the rail guided solution. This solution was based on the current solutions for the arm with aspects inspired from roller coasters and library ladders. Currently, a rail system is used with the SABRE arm to clean bridges. This proposed solution will not be a linear rail solution, but rather a large ramp rail. The ramp rail design will provide the arm with the ability to move up and down the rail to clean the floor and walls of the tank. Rail systems are stable and the platform supporting the arm can be easily stabilized in a locked position. Additionally, rails can be easily assembled and disassembled to be loaded in and out of the tank. As previously stated, the primary performance specification is that the stand remain stable despite the thrust created during sandblasting. The secondary specification requires the parts of the stand to be loaded and removed through the tank's entry hatch. A full scale prototype of the robot arm platform will be created and serve as proof of concept for this design. The prototype will be thoroughly tested and analysis will be performed to show the effectiveness of the design solution. Prior to building and testing the platform prototype, there are intermediate steps the design team will be taking. Suez associates will be consulted on the proposed solution and their feedback will be considered into the final design solution selection. The design team will also conduct feasibility analysis on the five proposed design solutions to ensure that prototype will work to Suez's standards. Following these actions preliminary computer aided design (CAD) will be modeled of the solution. This model will be used to run a finite element analysis (FEA) to confirm its stability given certain loads. Simultaneously with CAD and FEA, materials for the stand will be selected. Once all the models and materials have been finalized and approved by both Suez sponsors and faculty advisors, prototype construction will begin.

Nomenclature

Ground Tank: A cylindrical water tank with a base that is fixed on the ground
Cycle time: The time that SABRE's autonomous sandblasting arm takes, start to finish, to complete sandblasting the 3 meter by 3 meter square section
XXX: Requested data that is not yet been provided

Main Body

Introduction and Background

Suez Advanced Water Solutions/Utility Service Company Inc. is a water systems company that provides services such as clean drinking water, waste treatment and recycling to over 7.5 million people across North America. In order to provide quality water service, Suez maintains over 6,000 water tanks; maintaining water tanks requires cleaning the inner surfaces of the tank every 8 to 10 years. Currently, cleaning the water tanks requires sandblasting and repainting the tanks using manpower and manual hoses; this process is both inefficient and costly. Suez has acquired an autonomous sandblasting robot arm that will reduce both the time and financial requirements for cleaning ground water tanks. In order to utilize the autonomous robot arm, Suez requires a platform that remains stable while the arm is sandblasting and is easily moved to a new location after the cycle time has ended.

The autonomous sandblasting robot is a six foot arm that has six degrees of freedom which enables it to sandblast a 3 meter by 3 meter square in one cycle. The robot scans the potential range for sandblasting using a structured light infra-red laser. An operator then selects the surface area to be sandblasted and activates the arm using a remote user interface. The arm has previously been used to sandblast bridges and Suez desires to expand the use of the technology to their water tanks. In bridge applications, the arm was mounted on a rail system which provided stability during blasting and the ability to move horizontally in between cycles. In Suez's application, permanent rail systems would compromise the integrity of the water tank and are not a feasible mounting option. Instead, Suez requires a mounting platform that can support the 25 kg arm, provide stability during the sandblasting cycle, and allow for horizontal and vertical movement in between cycles while not damaging the integrity of the water tank materials.

Applying the autonomous robot arm within Suez water tanks presents unique design challenges when conceptualizing a solution. For initial applications, Suez will be employed in ground water storage tanks. Ground tanks are cylindrical with dimensions ranging from 8 ft to 100 feet in diameter and 30 feet to 100 feet in height. All ground tanks are accessible through an entry hole with a diameter of 30 inches. In order to increase efficiency of sandblasting, the amount of human intervention in between cycles should be minimized. The proposed solution for the autonomous arm robot platform will be able to be assembled within the water tank; similarly, all parts necessary for the function of the robot must be able to transported into the tank through the entry hole. A user interface with the ability to remotely control the movement of the platform between cycles will be included in a the platform solution. Finally, visual feedback will be required for the operator to successfully maneuver the platform within the tank. With the successful creation of this stabilizing platform, Suez expects to increase efficiency of tank cleaning by 70%.

Existing Products, Prior Art and Applicable Patents

There are a plethora of existing solutions used for stabilizing robotic arms. Some of these solutions include: rails, sturdy tables, ground mounts, and a few others. The majority of these solutions are designed for robotic arms used in factories, labs or other relatively static environments. These solutions primarily use mounting brackets to secure the arm to a static surface. Currently, SABRE is mounting the autonomous robotic arm on rail systems. The rail system allows the arm to be moved once the cleaning cycle has finished the designated area while also providing an easy locking mechanism and stable base for the arm when in operation.

There are few applicable patents addressing the current design problem that Suez is facing. Patent number US4518437A (assigned to Sommer Schenk AG) covers a method and apparatus for cleaning a water tank. More specifically, the patent describes an apparatus that has caterpillar tracks for movement. These tracks move by direction of a controller which has a compass and can be set on a course. The claim for this patent states that this is for an underwater cleaning apparatus. Additionally, this patent has a priority date of July 5th, 1982 and therefore is not currently enforceable. Patent number US3527336A (assigned to Associated Millwrights Inc) is for a guide rail system. The invention covers a system in which a device runs on rails horizontally and vertically. This is a similar type of design that is being considered for the robotic arm. By using the rail system, the device on the cart can remain very stable. The filing date for this patent was February 28th, 1968, so it does not have an affect on this project. Considering the current technology available, there are no applicable patents that will hinder the design solution for the autonomous robot arm platform.

Customer Requirements and Engineering Design Specifications

The main stakeholder for this project is Suez Advanced Water Solutions/Utility Service Company Inc. Suez has a high interest and a high influence. The tank cleaners have a high interest but low influence. The municipalities have a low interest but a high influence. The citizens in the municipality have a low interest and a low influence.

	Low Interest	**High Interest**
High Influence	Municipalities	Suez
Low Influence	Municipality Citizens	Tank Cleaners

Suez has provided very few requirements for the project. The product must:

1. Stabilize the robotic arm during sandblasting. Testing steps:
   a. The location of the base of the robotic arm should have no measureable displacement or rotation during the sandblasting process
2. Maneuver the base of the robotic arm within 5 m of every surface of the inside of a ground water tank. Testing steps:
   a. The base of the robotic arm should be able to be positioned such that the entire floor can be sandblasted.
   b. The base of the robotic arm should be able to be positioned such that all walls can be sandblasted.
   c. The base of the robotic arm should be able to be positioned such that the entire ceiling can be sandblasted.

There are a number of constraints that have been provided by Suez. The product must:

1. Be transported/assembled by a 3 man team
2. Fit within a 24 inch diameter round hole for tank ingress
3. Withstand the forces generated by the sandblasting arm
4. Withstand the sand and moisture generated by sandblasting

The following detailed engineering design specifications have been created based on the requirements and constraints above:

No.	Changes	D/W	Requirements	Responsible	Source
1		D	Stabilize the robotic arm during sandblasting		Suez
2		D	The base of the robotic arm should be able to be positioned such that the entire floor can be sandblasted		Suez
3		W	The base of the robotic arm should be able to be positioned such that all walls can be sandblasted		Suez
4		W	The base of the robotic arm should be able to be positioned such that the entire ceiling can be sandblasted		Suez
5		D	Break down into parts weighing less than 25 kg each		Suez
6		D	Be assembled in under 6 hours by a 3 man team		Suez
7		D	Each part must fit within a 24 inch diameter round hole		Suze
8		D	Withstand a maximum force of XXX N generated by the sandblasting arm		Suez

9		D	Withstand the sand and moisture generated by sandblasting		Suez

The importance of each specifications have been determined to be:

Specification	**Importance**
Stabilize the robotic arm during sandblasting	Main function
The base of the robotic arm should be able to be positioned such that the entire floor can be sandblasted	Main function
The base of the robotic arm should be able to be positioned such that all walls can be sandblasted	Secondary function
The base of the robotic arm should be able to be positioned such that the entire ceiling can be sandblasted	Secondary function
Break down into parts weighing less than 25 kg each	Hard requirement
Be assembled in under 6 hours by a 3 man team	Hard requirement
Each part must fit within a 24 inch diameter round hole	Hard requirement
Withstand a maximum force of XXX N generated by the sandblasting arm	Hard requirement
Withstand the sand and moisture generated by	Hard requirement

sandblasting	

Market Research

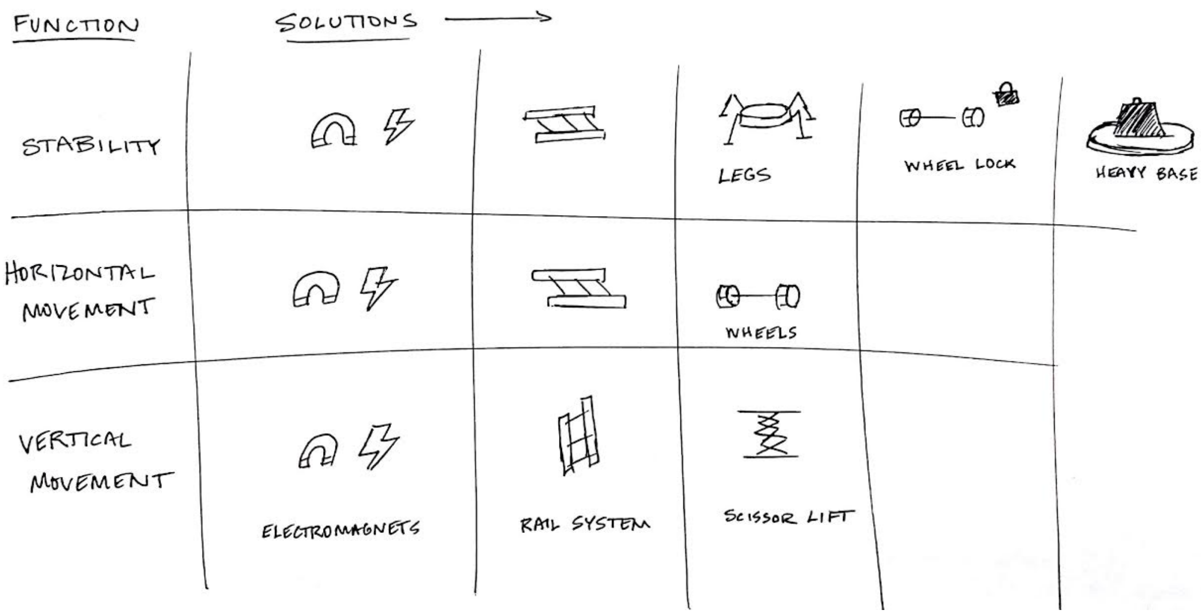
In order to provide 7.5 million people with water service, Suez maintains over 6,000 water tanks across North America. In order to maintain quality service, the interior tanks must be cleaned and repainted every 8 to 10 years. On average, Suez treats over 100 tanks per year. The cost of cleaning varies with the dimensions of the tank; however, sandblasting and repainting these water tanks can cost more than $200,000 per tank.

Currently, Suez uses manpower and handheld hoses to sandblast and clean the inside of these water tanks. The manpowered cleaning and painting process currently being employed requires 4 weeks for completion. With the recent acquisition of the SABRE Autonomous Blasting Robot, Suez has the opportunity to automate the sandblasting process therefore increasing the efficiency of the cleaning process. However, until a stable base for the arm is created, the arm cannot be utilized. Based on the number of tanks Suez currently maintains and the estimated addition of 25 tanks per year, there is ample opportunity for the autonomous sandblasting arm and the stabilizing platform to advance the cleaning process. With SABRE's estimate of increased sandblasting productivity by 70%, there is substantial financial benefit in Suez's adaptation of autonomous arm and base support. Once a prototype is developed, a study will be conducted with Suez operators to get feedback on the user interface and system.

Design Concept Ideation

Suez has the need for a platform system capable of supporting an autonomous robotic arm to sandblast the inside of water storage tanks. The functions of the design considerations must be able to remain stable while the robotic arm is operating. In addition, secondary functions include automated horizontal movement, automated vertical movement, and visual feedback to the operator to adjust position.

The primary function of the platform is to remain stable while the robot is in operation. Ideas for stability include the use of electromagnetics, retractable legs, locking wheels, and a rail system. Secondary functions of the platform include horizontal and vertical automated mobility within the tank. Ideas concepts for horizontal mobility include a system of motorized wheels, a rack and pinion system with electromagnetics, and a rail system. Idea concepts for vertical mobility include a scissor lift system, a rack and pinion system with electromagnetics, and a rail system. The morphological chart below shows the various functions as well as the proposed solutions to solve the functions.



Combining the categories from the morphological chart, five design concepts were created as possible functional solutions. The proposed solutions include a rail guided solution, an elevated platform solution, a wall climbing solution, a modular scaffolding solution, and an outrigger solution. The rail guided solution combines the rail system from the stability and vertical movement functions to create a ladder-like system for the arm to move up and down. The elevated platform system uses the wheels for horizontal movement and scissor lift for vertical movement. In addition, wheel locks will stabilize it on the ground, while electromagnets will stabilize the structure when vertically extended. The wall climbing solution combines the electromagnets with a rack and pinion system to simulate the motion of an inchworm. Two electromagnets will alternate being active for the structure to move. The modular scaffolding solution involves automated wheels and wheel locks for motion and stability. The wheels will be linked to communicate together and offer a flexible solution for future application. The outrigger solution uses retractable legs similar to a crane to stabilize the platform during operation.

From the preliminary concept designs, the outrigger solution appears to be the most feasible followed by the rail guided solution, the elevated platform solution, the modular scaffolding solution, and finally the wall climbing solution. The existing technology for hydraulic legs is already applied to cranes and would be applied in a similar manner for the platform base. The next feasible solution is the rail guided solution since Sabre is already using rails to service bridges. The main challenge presented in this solution would be automating the movement along the rails. The third solution is the elevated platform solution. Challenges of this proposed design involve the scissor lift fitting through the entry hole of the tank, and providing stability at the peak height of the lift through electromagnets. The fourth solution is the modular scaffolding solution. Although scaffolding is currently used in Suez's prototype design, the main challenge would be developing a series of wheels that can communicate together. Finally, the wall climbing solution appears the least feasible. Challenges with this design include having electromagnets strong enough to hold the weight of the arm and withstand the forces during operation and fabricating a prototype. However, the ability to tether the power source rather than batteries helps solve the problem of current wall climbing devices. In addition, this type of technology used in this application could push the standard in this industry.

Preliminary Concept Selection and Justification

In order to select designs for further development, the concepts were assessed using a decision matrix with criteria such as efficiency, portability, and stability. The decision matrix is displayed below in Figure XXX. The project team decided on 10 criteria upon which the concepts will be assessed. Each criterion was given a weight between one and five, depending on its perceived importance to the success of the solution, with a weight of five indicating "Very Important". The concepts were then given a score between one and five, with a score of one indicating "Poor Performance" and a score of five indicating "Excellent Performance" in each respective criteria. As a result of this assessment, the Guided Rail Solution and Wall Climbing Solution scored highest with scores of 154 points and 121 points, respectively.

Criteria	Weight	Designs				
		Guided Rail Solution	Elevated Platform Solution	Wall Climbing Solution	Modular Scaffolding Solution	Outrigger Solution
Portibility	4	4	2	4	3	2
Stability	5	4	2	5	3	3
Reach Height	3	4	3	5	5	1
Creativity	2	3	2	5	3	1
Existing Technology	3	3	5	1	4	5
Efficiency	4	5	3	4	2	3
Durability	3	5	2	2	3	2
Durability	3	5	2	2	3	2
Safety	5	5	5	4	4	5
Simplicity	4	4	2	1	2	2
Total Weighted Score		154	103	121	114	100

The feasibility of the five proposed designs was also analyzed in order to determine the design with the highest potential success. The Guided Rail Solution draws inspiration from the rolling ladders typically found in a library setting. Given that the current applications of the Sabre robotic arm utilizes rails for stability and mobility, the use of rails in the water tank application is promising. The rail system can be designed in such a way that it breaks down into long components, capable of passing through the small entry hatch of the ground tank. The cross members of the rail system would provide support points for the arm platform to mechanically hold its elevation. To increase stability, pneumatic pistons could be added to the cantilever end of the horizontal track, wedging the assembly between the ground and the floor.

The Inchworm design concept affords Suez the ability to control the arm with little human interaction. When compared to the other concepts, its small footprint will be able to maneuver around the tank with ease. While the robot will not be capable of transferring from the floor to the wall, it will be about to move vertically and radially on the wall without assistance. This is a feature that some of the other concepts are not capable of. Due to the tethered requirement of robotic arm, the robot will not be required to carry its power source in the form of batteries. This is one of the significant challenges of a electric wall climbing robot that is avoided in this application.

Along with feasibility, the associated potential risks were evaluated with respect to each design concept. The current design of the Guided Rail Solution's ramp positions the arm in in such a way that the base is facing away from the surface of the wall. This positioning may reduce the effective area of the arm at each ramp position, impacting the solutions efficiency. The reach of the arm will need to be investigated in this position to determine if the efficiency is negatively impacted. A possible resolution of this issue is a redesign of the ramp to position the base of the arm tangentially or facing the wall but would require a more complex assembly and would limit the access to the floor of the tank.

The Inchworm solution is perhaps the most ambitious of the concepts that we have generated. Due to the complexity in design and controls, this concept may be hard to fabricate and deliver to the client in 5 months. One of the potential risks is possibility that the electromagnets will not be strong enough to hold the equipment against. The tanks walls are constructed with steel plate that are painted for corrosion protection. This will limit the holding strength of the electromagnets, which are rated for rust-free unpainted iron. If the holding strength is significantly diminished, the number of magnets needed to hold the robot against the wall might become unreasonable. Another risk with this design is the potential for power loss. If the equipment loses power at any point, it will become unsecured from the wall and fall, unless properly tethered. The feasibility and potential risk analysis will continue and be combined with preliminary CAD models to make a final recommendation on a design solution.

Summary & Next Steps / Project Deliverables

Based on the understanding of the problem and market research, multiple design concepts have been developed and analyzed. The rail guided solution appears to be the most beneficial and feasible solution given the time and engineering constraints associated with this project. The rail solution offers stability within the rails while simultaneously providing vertical mobility along the walls. In addition, the ability of modular construction would allow separate components to fit through the entry hatch.

As the project continues to move forward, the next steps include meeting with the sponsor to discuss the design ideas, meeting with Dr. Lipkin for consultation, and developing preliminary CAD designs for the solution. Based on input from Suez, Dr. Lipkin, and further analysis of each concept, a final design selection will be made and prototyped to be demonstrated to Suez.

References

Johnston, Kenneth H. Guide Rail System. Associated Millwrights Inc, assignee. Patent US3527336A. 8 Sept. 1970. Print.
https://patents.google.com/patent/US3527336A/en?q=rail&q=systerm

Sommer, Peter. Method and Apparatus for Cleaning a Water Tank. SOMMER, SCHENK AG, A SWISS CORP., assignee. Patent US4518437A. 21 May 1985. Print.
https://patents.google.com/patent/US4518437A/en?q=water+tank&q=cleaning

"Water Services." *SUEZ Water Advanced Solutions*. N.p., n.d. Web. 18 Sept. 2016.
http://www.mysuezwater.com/about-us/water-services