Building A Robotic Mechanism for Cleaning Trench Drains

Mr. Adithya Kaushik, University of Cincinnati

Graduate Student Mechanical and Materials Engineering College of Engineering and Applied Sciences University of Cincinnati

Dr. Janet Dong, University of Cincinnati

Dr. Janet Dong is an associate professor in the College of Engineering and Applied Science at the University of Cincinnati. She is the director of UC Center for Robotics Research. She holds a BS degree in Mechanical Engineering and a MS degree in Manufacturing Engineering. She received her Ph.D. in Mechanical Engineering from Columbia University in 2003. Her academic interests include manufacturing engineering technology, process planning, control and automation, robotics, and manufacturing automation integrations.

Dr. Ce Gao, University of Cincinnati

My current research aims at utilizing modern machine learning and data analytics techniques on infrastructure management, assets condition prediction and integrated infrastructure management systems. My past experience also involves building energy simulation, LEED, and robotics design.

Dr. Hazem Elzarka, University of Cincinnati

Dr. Hazem Elzarka is a Professor of Civil Engineering at the College of Engineering and Applied Science at the University of Cincinnati, USA. He is a registered professional engineer (PE) in the State of Ohio, a LEED Accredited Professional (LEED AP), and a Certified Energy Manager (CEM). He has consulted for federal and state agencies and major US and international construction firms. His consulting/research work is in the areas of Infrastructure asset management, Green Buildings, applications of advanced computer technologies in the construction industry, and Total Quality Management. He has recently served as the principal investigator of several research projects for the Ohio Department of Transportation related to infrastructure asset management.

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Adithya Kaushik
Graduate Student
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

Dr. Janet Dong
Associate Professor
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

Ce Gao
Doctoral Student
Department of Civil and Architectural Engineering and Construction Management
College of Engineering and Applied Science
University of Cincinnati

Dr. Hazem Elzarka
Professor
Department of Civil and Architectural Engineering and Construction Management
College of Engineering and Applied Science
University of Cincinnati

Abstract - The purpose of this project is to develop a novel method for the cleaning of trench drains. It deals with the design and conceptualization of a robot which fits into the drain and cleans it without interfering with the surrounding traffic or the drain itself. The entire cleaning process includes breaking the dirt down, sucking the dirt, and transporting it to a collection unit. Our method combines the entire process into a single mechanism-a robot, and it is considerably faster than the previous methods used for the purpose. The robot uses a drive system to move inside the drain drive is bidirectional to control the robot forward and backward as needed. The robot is controlled remotely. The robot has a cutting assembly, housing to host the drive system, and square suction tube on top of the housing. The cutting assembly consists of cutting arm and three metal brushes installed onto the arm. The cutting arm is used to better facilitate the suction and the metal brushes are used to loosen the debris and break it down. The suction tube is connected to suction unit to suck dirt away to a desired location. The overall design of the robot is discussed in detail in a separate paper. This paper will focus on the discussion of manufacturing aspects of the robot. It provides the machining procedures associated with the fabrication of the robot. It also states the challenges faced in machining and how the problems were solved.

Keywords – Bidirectional Control, Cutting Arms, Cutting Assembly, Drive System, Robots

I. INTRODUCTION

Trench drains are commonly installed in roadway depressions along the shoulder or in gore areas. They are typically installed in these locations as a result of shallow pavement cross slopes that cannot be drained into a ditch or catch basin. Without routine maintenance, the road grit accumulates in the bottom of the drain and quickly gets root bound by the noxious weeds and other vegetation. Once this happens, it becomes very labor intensive to clean and reestablish flow. Currently, trench drains are cleaned manually or using a sewer cleaning truck. Both the manual process and the current procedure of using a sewer cleaning truck are not safe as they both require highway technicians to walk along the drain during cleaning and thus expose them to heavy traffic. A safer process that can clean the entire length of the drain from one location is needed.

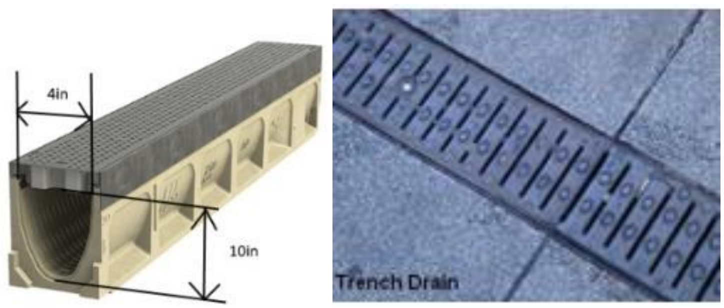

Fig. 1. Trench drain with maximum diameter 4”and height 10” (left); Top view of trench drain (right)

A trench drain, as shown in Figure 1, is comprised of two sections, the hollow cavity and the grate to enclose it. The grate is used to enclose the drain and is the only part visible from the top. The hollow cavity is where the dirt eventually settles. The hollow cavity in the drain is sloped with a radius of curvature of 2 inches at the bottom. [1]

There were several methods used for the cleaning of trench drains. Two of these are listed below:

1) Manual cleaning was one of the earliest methods used for this purpose. It involved opening each section of the drain manually and performing the cleaning through brushes. This method was slow and took time, i.e. cleaning rate was about 30ft/hr, and it required a lot of manpower for efficient cleaning.
2) Water jetting cleaning method involved cleaning the drain using a high-pressure nozzle, and water from nozzle forced the debris to one end of the drain. It was propelled forward by reverse water jets. The main problem with this method was that it took a lot of manpower during operation and led to a lot of water wastage. Another problem was that the splashing of water while cleaning resulted in the debris spraying on to the roads around the drain, leave a very messy road behind. [2]

To overcome above problems, there is a need for a new method which utilizes minimum manpower, efficiently transports the debris to a desired location, and is faster than the previous methods, and leaves a clean road. This paper will discuss a novel method to clean trench drains.

II. PRELIMINARY RESEARCH

Site Inspection*:* Trench drains on various sites were inspected for conditions and dimensions, and the interviews with drain administrative personnel were conducted. It was found that most of the trench drains had soil deposition at the bottom. In some cases, the drains were completely blocked by soil and vegetation.

The drain was 10 inches in total depth, 4 inches in width and with a curved bottom having a radius of curvature of 2 inches, see figure 1. The drain runs throughout with continuous sections, each section of 1 meter (39.3 inches).

Customer Needs*:* Highway users and highway administrative personnel are the customers for the project. From the site inspection and the problems faced on cleaning, customers need a new cleaning method capable of accomplishing the following tasks:

1) It should be able to clean a section of the drain 50 ft to 300 ft long.
2) The time for cleaning should be at most 50 minutes for a section of 50 ft at a rate of 1 ft per min, which is faster than manual cleaning.
3) The cleaning should clean at least 75% of the drain cross section along the entire length required. This is taken to set a standard for the mechanism to be tested against.
4) The cleaning should be controlled from a single point for the entire section of drain. Thus, the range of control should be more than 100 ft.

Initial Challenges*:* There were several challenges faced initially, pertaining both to the operation as well as the design of the cleaning mechanism.

The Operational Challenges are some of the following:

1) The new cleaning method had to be designed so that it had a minimum interaction with the traffic on nearby highways.
2) The cleaning had to be done without use of any additional resources such as water which might lead to wastage.
3) The debris had to be cleaned in an efficient manner such that it is directly conveyed to the vacuum collection unit at the starting point. All factors such as debris spilling onto the roads, etc. had to be considered and minimized.
4) The designing had to be done in such a way that the cleaning could be operated from a single location for minimum interaction with external factors such as traffic.

There were some Design Factors that needed to be considered which would be the basis of deciding the various components in the mechanism. Some of these are given below.

1) The length of the drain section that needs to be cleaned by the mechanism should be obtained.
2) The time within which the cleaning is to be accomplished had to be determined
3) The percentage of the drain cross section that needed to be cleaned to ensure satisfactory cleaning was to be observed.
4) The amount of manpower that is needed for the whole process should be minimal.
5) The process should be automated with minimum human intervention.
6) The debris cleaned should be collected and transported to a separate location to avoid littering around the drains.
7) The hindrance to oncoming traffic should be minimum as most of the drains are next to the highways.
8) The operation should be safe to all personnel involved and should not harm the drains.

III. MANUFACTURING FEATURES

Due to the limited space available inside the drain ie less than 4”x10”in cross sections the entire size of the robot should be able to fit in this confined space. The fabrication of the prototypes had to be done with the following considerations.

1) The frame for the entire prototype is made from Aluminum sheet metal due to them being lightweight and corrosion resistant [3].
2) The robot fits inside the drain smoothly without encountering drain surfaces side or top while in operation.
3) Most parts are to be welded. The welding tolerance must be kept as minimal as possible to avoid interference with the robot operation inside the drain. Certain filing operation on welds may be necessary to smooth out the joining surfaces. Moreover, the welding needs to be done at the frame location where minimum load would be applied to keep an optimum strength of the frame [4].
4) Prototypes should be fabricated with their modularity as a priority. A ‘modular’ design has the advantage of each part being an entire system itself. This ensured that parts of the mechanism could be used separately as needed. And it also makes maintenance or repair easy and fast.

Once these features are incorporated in robot, further modification and testing would lead to better efficiency and performance while robot is in operation.

IV. DESIGN OVERVIEW

Two prototypes are designed and analyzed from the required design requirements. The design for the first prototype is shown below in Figure 2. The overall dimensions of the prototype are 33 inches in length x 4 inches in width x 9.75 inches in height.

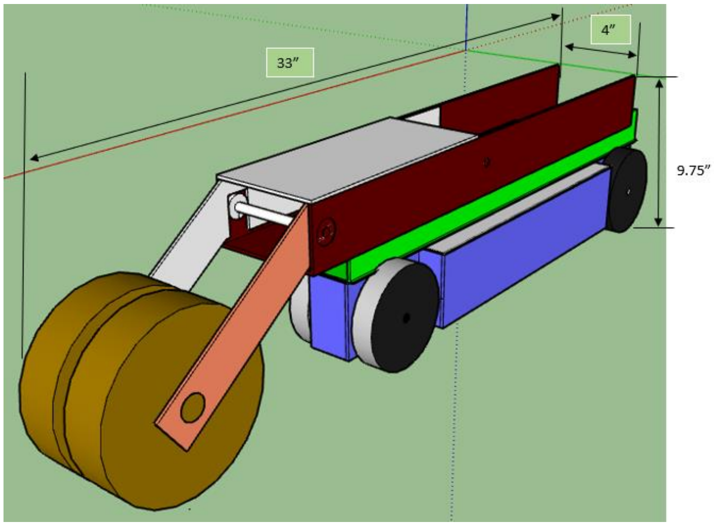

Fig. 2. Design of Prototype 1

There are three major subsystems, namely the drive system, suction assembly, and the cutting assembly, in the first prototype design. The drive system consists of the base frame and drive system, which has the drive motors, gears, batteries, and the wheels. It is responsible for driving the robot as intended. The suction assembly is attached to the top of base frame of the drive system which is used for the suction and transportation of the dirt from the drain to the desired collection unit. The size of the hose is calculated to accomplish optimum suction [4]. The cutting assembly comes on top of the suction assembly which involves softening the debris for the suction to be efficient. Metal brushes are installed on this assembly in such a way that the brushes encounter the dirt first and act on them with their rotating action. The prototype was designed to sweep the dirt into the suction inlet while traversing the drain surface. However, it was found to have certain limitations during operation.

A second prototype was designed after preliminary testing on the first prototype showed that there were several challenges for smooth operation of the robot. This prototype is shown in Figure 3.

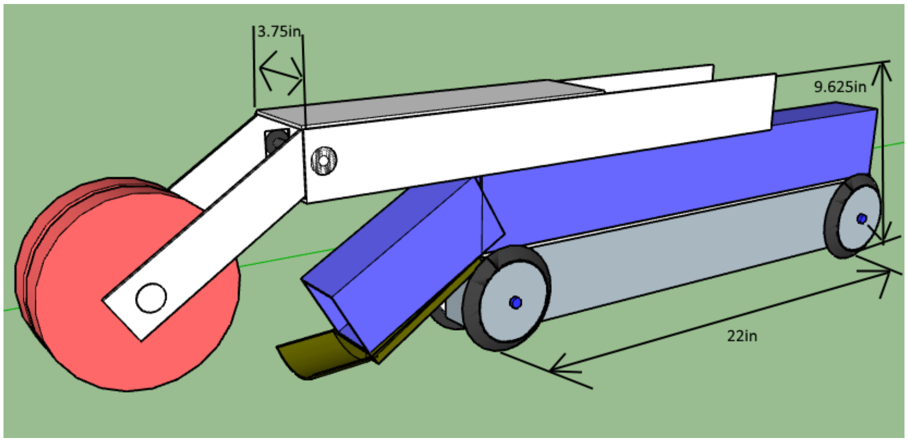

Fig.3. Design of Prototype 2

This prototype contains the same mechanisms as the first i.e. Drive System, Cutting Assembly, and the Suction Assembly. However, it has a few design changes in each of these systems. The robot moves as a four-wheel drive where a dual shaft motor is attached to each set of wheels. The motors are arranged to make them move in opposite directions to each other so that all the wheels can move in one direction. There are four wheels attached to the frame which are each of 4 inches in diameter and 0.4” in thickness. These wheels are curved instead of being flat and have a slight radius. This is done so that the contact area between the rubber wheel and the drain can be increased and the robot can move smoothly inside the drain. Additionally, it also contains only three metal brushes instead of four to ensure smooth operation inside the drain.

V. PROTOTYPE FABRICATION AND ASSEMBLY

Two prototypes are fabricated. The fabrication was accomplished based on the robot requirements for smooth functioning inside the drain [5].

Figure 4 shows the completed first prototype developed. There are three major subsystems, namely the base frame and drive system, suction channel and hose, and the cutting assembly. The base frame and drive system consist of base frame which host the drive system and carry or support other components from other subsystems, a shovel to push the loosen dirt forward, and the drive motors, bevel gears, batteries, and the wheels. The drive system is responsible for driving the robot as intended path and speed. The suction channel and hose are mounted on the top of the base frame from the drive system, which is used for the suction and transportation of the dirt from the drain to the desired collection unit. The cutting assembly includes cutting arms and metal brushes. The cutting arm is mounted on top of the suction channel and at the front end of the channel. The metal brushes are installed on the far end of the cutting arm assembly in such a way that the brushes encounter the dirt first and act on them with their rotating action. The function of the cutting assembly is to soften the debris for the suction to be able to function and efficiently function.

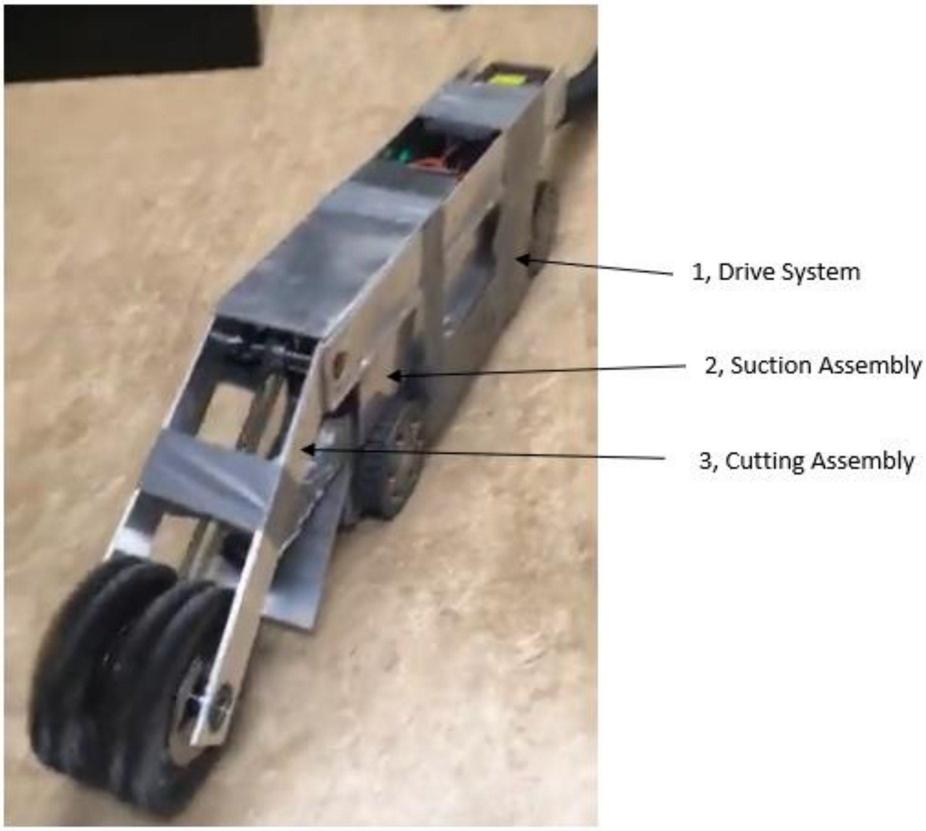

Fig. 4. Fabricated Prototype 1

Figure 5 shows the drive frame along with detailed list of its parts respectively. The frame is designed in such a shape that all components except the wheels are housed inside the frame. The wheels are installed on shafts, one of which is coupled with the drive motor using bevel gears. This connection enables transmission of power for perpendicular shafts. The battery and other electronic components are housed behind the motor. The drive cover is then placed on this arrangement making the drive compact and modular in design.

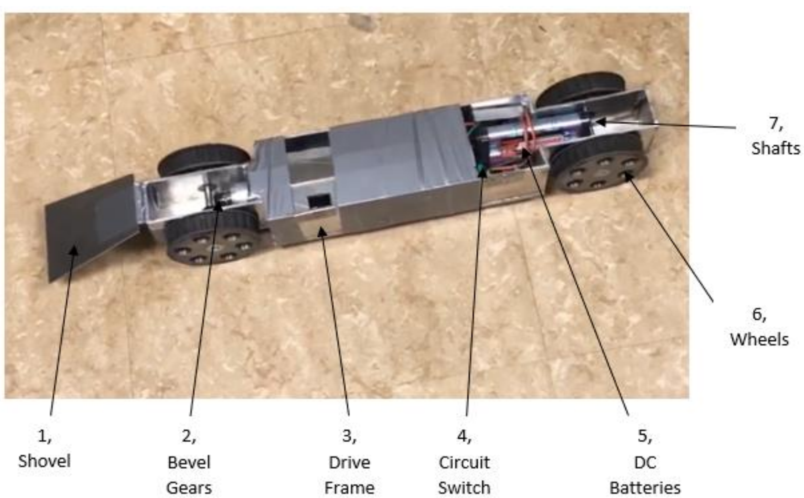

Fig. 5. Fabricated drive system of prototype 1

Figure 6 shows the cutting assembly with metal brushes along with a detailed list of its main components respectively. The cutting arms have been designed in such a way that the metal brushes are a bit lower than the center of the drain height wise. This is done to ensure that the dirt in the lower region gets loosened first. Due to this, the debris in the upper portions would collapse with no support and fall at the bottom of the drain. This will enable suction to work smoothly as most of the debris will be at the drain surface.

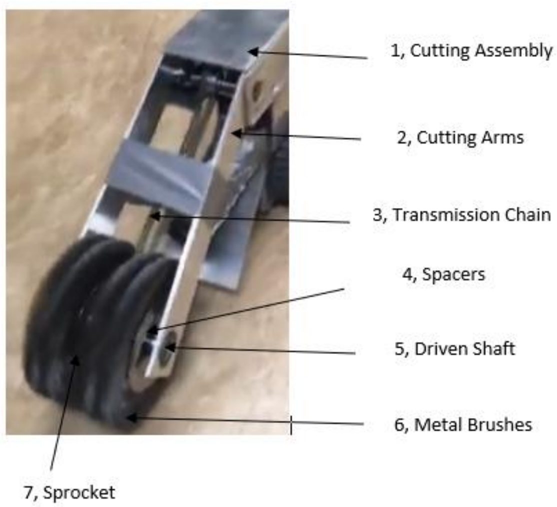

Fig. 6. Fabricated cutting arms of prototype 1 with 6” metal brushes

Although the first prototype theoretically was designed to clean the drains from the inside, there were several problems observed during the preliminary tests conducted. They are listed as follows.

1) During the test, the bevel gears in the drive systems were found to disengage repeatedly. This disengagement was observed when there was some resistance (presence of dirt) to the robot movement.
2) The robot could not move at all inside the drain. The wheels, being flat widthwise, did not have enough contact with the drain surface, which was curved.

Based on the observations from the previous test, it was decided that the whole drive system had to be changed. The robot had to be four-wheel drive for better control of wheels with two DC Dual Shaft Motors, one each for the front and rear set of wheels. It was also decided that the wheels had to be redesigned with a curved profile resembling that of the drain surface.

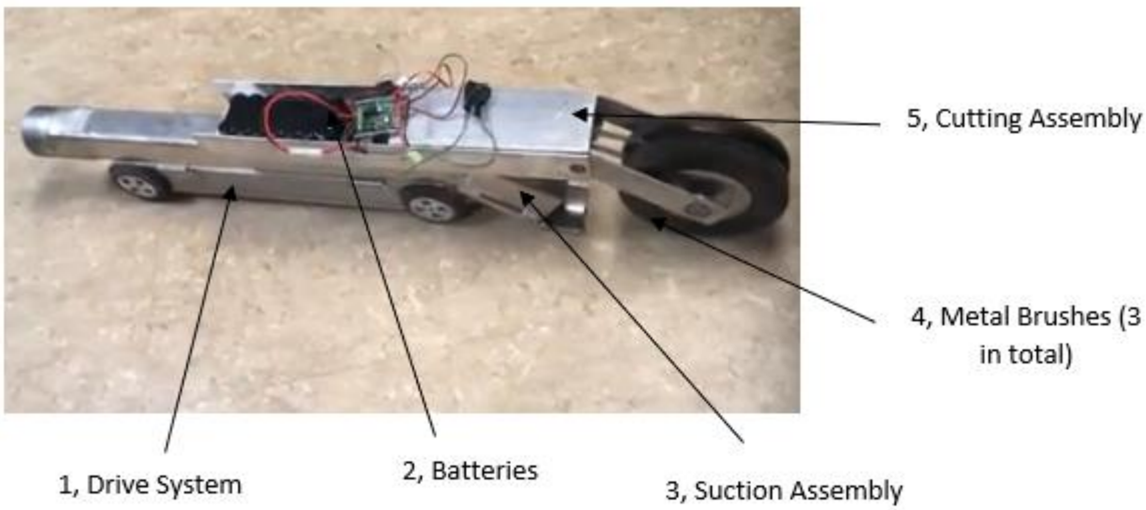

Fig. 7. Assembled prototype 2

The completed second prototype is shown in Figure 7. This prototype was mainly designed as an improvement on the first prototype and overcomes many of the obstacle faced by the previous model. The modifications of this models are discussed in this section.

1) The wheels were custom designed based on the drain dimensions. The previous prototype had cylindrical pulleys which were used as wheels. This however led to a problem when the robot was in operation inside the drain. Due to the profile of the wheels and the curved portion of the drain, the contact between the rubber and the concrete was very less and only the edges of the wheels touched the drain. This made the movement of the mechanism very constrained and the robot repeatedly had to be stopped. To overcome this, wheels were machined with a rubber material coated on a curved profile to account for the dimension of the drain.

2) The bevel gears in the first prototype constantly disengaged while in operation. This was overcome by replacing the single drive motor with two dual shaft motors, making the overall robot all-wheel drive instead of front wheel drive. This also provided more traction to the drive system.

Figure 8 shows the revised drive frame of the second prototype. The frame is again constructed such that all components except wheels are housed inside the drive frame. The batteries and other electronics are housed between the two motors. The all-wheel drive also provides better grip and traction and hence, there is an overall lesser chance of the robot getting stuck due to excessive debris.

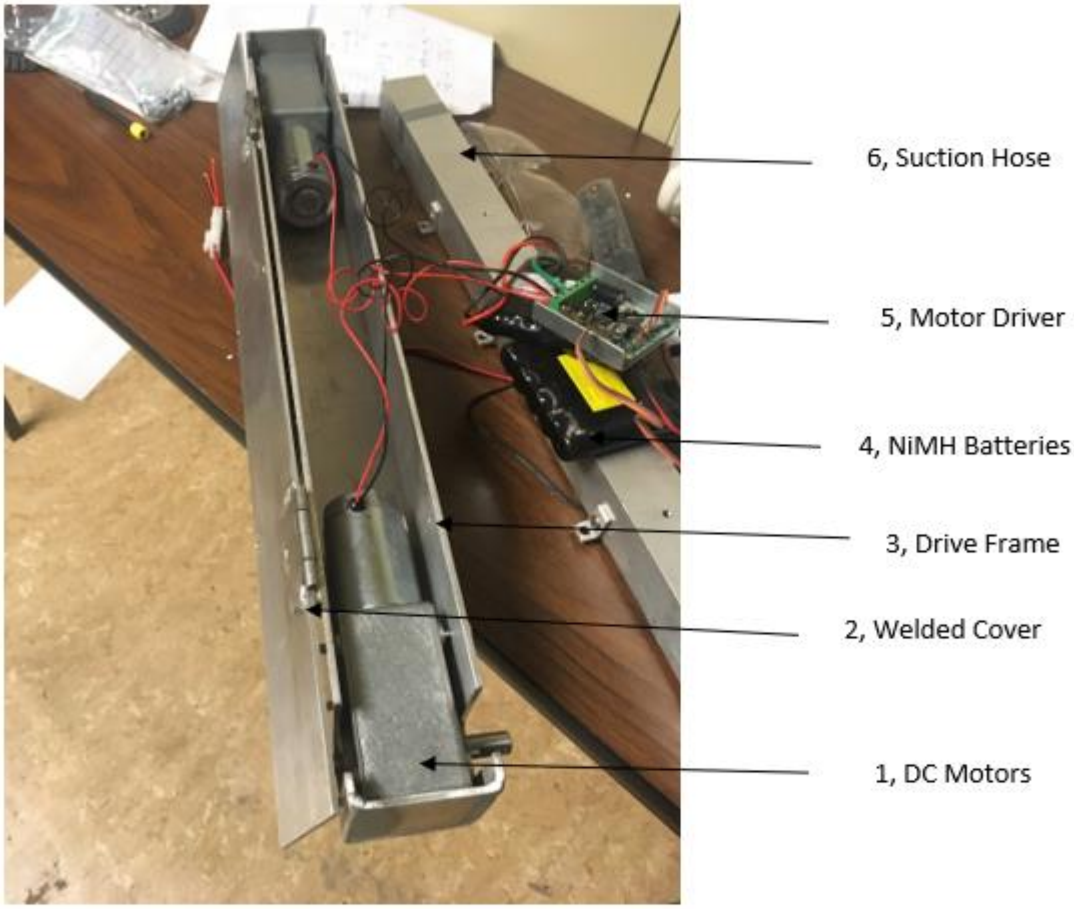

Fig. 8. Drive System of Prototype 2

VI. TESTING AND RESULTS

The final prototype was tested in a model drain to see the overall performance with suction. Suction used was GUARDAIR cannister vacuum with 15HP. The test was carried out for three different inlet sizes, namely 1.5”, 2.5” and 3.5”. The test was carried out for both dry and wet debris. A total of six combinations were tested where the performance of robot for dry and wet debris was observed for each of the inlet sizes. The following results were observed.

	1.5 in inlet	2.5 in inlet	3.5 in inlet
Dry Debris	Picked up most Debris, but hose can be easily stuck	Picked up some at least half of the debris. The chance of getting stuck was reduced	Couldn`t pick up any debris. The hose can hardly be stuck
Google Drive File Name	1.5 dry	2.5 dry	3.5 dry
Wet Debris	Picked up most Debris, but hose can be easily stuck	Picked up some less debris than dry debris. The chance of getting stuck was reduced	Couldn`t pick up any debris. The hose can hardly be stuck
Google Drive File Name	1.5 wet	2.5 wet	3.5 dry

The robot performs better when the clearance between the metal brushes and the hose is larger. The cutter can be extended to allow more time for the suction to act on the loosened debris particles. A more powerful vacuum force is needed at the source. Based on the inlet sizes tested, it is observed that the large the size, less the chance of debris getting stuck. However, larger the size, more the suction power needed.

VII. CONCLUSIONS AND FUTURE WORK

The field tests have demonstrated that the robot prototype's driving and cutting systems work as intended. More work needs to be done on the robot to ensure that the loosened dirt is efficiently sucked by the vacuum system as the current prototype is unable to pull a long suction hose behind it. Also, additional work is needed to make the robot more heavy duty to enable the robot to move over different types of debris and to make it water proof. The testing of the robot was done, and the results have been summarized separately in another paper dealing with the performance of both robot prototypes.

The second prototype provides a better cleaning efficiency as well as smooth operation when tested inside the drain. This prototype also provides a larger contact area while cleaning due to the use of two brush sizes. This mechanism also was found to be more robust while in operation as all the components were welded with the main frame.

Overall, though the second model worked smoothly inside the drain, more research and testing need to be carried out to determine the optimal cutting speeds and feed of the robot. Some of the other problems occurring after testing both the models are discussed below.

1) A more powerful Suction force should be provided to the mechanism which compensated for the increase in hose length when the robot moves forward in the drain. This will ensure that the dirt is sucked even when the robot has moved a considerable distance inside the drain.
2) The metal brushes need to be connected more robustly to avoid lateral sliding during operation. For this, a sub assembly needs to be added to the cutting arms to hold the brushes in place.

3) The shovel design for the second prototype needs to be modified to avoid debris getting stuck on the underside of the hose inlet. This causes improper suction and inhibits the robot motion going forward. The shovel needs to be sloped to facilitate the collection of debris in front of the hose inlet for optimal suction.
4) The curved wheels used in the second mechanism were found to compress due to the weight of the robot. To avoid this, harder rubber needs to be used for the wheel construction to more it more stable under load.

The robot prototypes proved the concept of conducting confined cleaning inside the drain as proposed initially and provide an initial model to improve upon. With the success of building such prototypes, it opens the door of using robots to do cleaning inside the pipe, tunnel and similar scenes along the line.

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