Modelling and design of a drain cleaning robot

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Abstract. Underground sewers collect waste from domestic and industrial buildings. These pipes are designed to carry only liquid and semi-solid wastes such as soap water and human excrement. However due to improper disposal, solid waste materials such as rags, plastic waste, condoms, sanitary napkins, white cement etc. are also found. Since the pipes are not meant to carry these wastes, they cause blockages. Apart from sewer drains housing societies with sewage treatment plants (STPs) also face this problem. Clearing these blocks either require a human worker, which endangers human life due to presence of toxic gases, or a high-pressure water hose cum suction machine which is very expensive. The aim of this paper is to design an automatic robot which will be able to clear blocks quickly at a much lower cost without any threat to human life. The robot will be lowered into the sewer pipes through a manhole. It will propel itself till it reaches the block then clear the block. The robot is tethered by data cable for communication and to prevent it from flowing away. A rope is used to retrieve the robot once the block is cleared.

1. Introduction
According to the Times of India, since 1993 to 2019 there have been 620 sewer deaths in India. Of these Tamil Nadu and Gujarat have had the highest number of cases. Between December 2013 and June 2019 totally 53,598 manual scavengers have been identified. So far, no individual or entity has been convicted in manual scavenging cases. DMs and other subordinate officers are authorised by The Prohibition of Employment as Manual Scavengers and their Rehabilitation Act 2013 to ensure that no person is engaged as a manual scavenger and ensure investigation and prosecution of individual or entity contravening the provisions of the Act. Despite this manual scavenging still prevails due to cheap availability of human labour and lack of understanding of risks involved in manual scavenging [1].

Sewer pipes contain organic wastes. Underwater, in the absence of oxygen, these wastes are decomposed by anaerobic bacteria and release gases such as Hydrogen Sulphide(H2S). Methane and Carbon Monoxide (CO). These gases are highly toxic to human beings. They are deadly because they cannot be detected by human beings. H2S initially gives a smell of rotten eggs but quickly causes olfactory fatigue. It causes respiratory problems, eye irritation, fainting and at high concentration sudden death. CO disrupts oxygen distribution in the body. Haemoglobin has greater affinity to CO than to O2. Thus, it binds with CO causing lack of oxygen in body tissues. Methane is highly flammable and increases risk of fire. These toxic gases are the reason for the

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scavengers and manhole cleaners [2]. Due to the presence of toxic gases the sewage cleaner faints. As the next person goes in to check, he faints too. In this manner a single incident causes a chain of deaths claiming the lives of many people. Thus, manual scavenging should not be practiced. In order to clear blocks caused by unwanted solid wastes, the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) deploys a Jetrodding machine. It consists of a high-water pressure hose connected to a water tank placed on a lorry. The setup is connected to a motor and a pump. The hose is lowered into the sewer pipe and super high-pressure water is used to clear the block. The CMWSSB also uses Jetting cum suction machine and a SuperSucker machine. These machines cost above ₹40-50 lakhs. Pipe length between two manholes varies from 30 m to 42 m. The sewer pipes vary from a diameter of 150 mm to 750 mm. The pipes are made of Stoneware, Cast iron, K7 and Ductile iron.

In Kerala a startup called Genrobotics has designed a robot named “Bandicoot” for manhole cleaning. The purpose of this robot is to replace manhole cleaners and manual scavengers. However, the robot is not capable of clearing blocks in the pipes since the robot uses a claw to vertically lift waste from manholes. This paper suggests a system which is a bridge between cheap manual labour with risk to human life and the expensive machines being currently used [3]. While designing an underwater vehicle some design specifications must be considered. Shape of body can be either torpedo or non-torpedo. Torpedo shape has less drag, more speed and longer range. However, it requires some translational speed to keep control. Non-torpedo shape is more controllable at lower speeds. But, due to large form factor these vehicles experience a higher drag. Each has its own advantages and disadvantages [4]. There are three types of navigation techniques that may be considered. Inertial navigation: Uses gyroscopic and accelerometer sensors to detect motion of vehicle in all 3 axes. It is significantly better than dead reckoning. Acoustic navigation: Uses acoustic transponder beacons to allow the vehicle to determine its position. Most common methods are long baseline (LBL) which uses minimum of two widely separated transponders and ultrashort baseline (USBL), which uses GPS calibrated transponders on a surface vehicle. Geophysical navigation: Uses physical features of the environment to calculate position. Features may be natural or artificially deployed [5]. Of these, only inertial navigation is viable for this project. Thus, an inertial measurement unit compatible with the controller used (Raspberry Pi) was chosen.

Power source of the vehicle must be chosen according to the power requirements. Higher the speed, more power will be required for propulsion and thus range will reduce. For low speeds, power needed for propulsion is low and thus range is high. Power consumption of hotel load, which consists of all loads except propulsion – navigation, sensor and control, remains constant. Lithium polymer batteries because of their high energy density and power to weight ratio are very attractive alternatives to lithium ion lead acid batteries [6]. In 2016 students of ICE department from SRM University designed and fabricated a small remotely operated robot to detect blockages in sewer pipes. The robot has three thrusters, two horizontal and one vertical. The robot is controlled by a data cable. Power is transmitted from a 12V DC lead acid battery through the cable. Robot motion is controlled by viewing the robot path through an infrared camera mounted on the front of the robot. Propeller direction is controlled through two Double Pull Double Throw (DPDT) switches [7]. In 2012 an autonomous sewerage blockage detector was proposed. The robot uses ultrasonic sensors to detect turns and blockages. Walls are detected by interrupts of ultrasonic sensor. The pipe is blocked if sensor system finds walls in both direction of the pipeline. Distance of the blockage from manhole is calculated using the distance calculation system and displayed at ground station [8].

Autonomous underwater vehicles for scientific and naval operations discusses the work done and scientific publications derived from the AUV programme at NATO Undersea Research Centre which initiated a joint research project with MIT [9]. Underwater obstacle avoidance and path planning describes a framework for segmentation of sonar images. It tracks underwater objects and performs motion estimation. The proposed system is capable of obstacle avoidance as
well as path planning. It performs well in complex environments with fast moving objects [10]. Underwater autonomous manipulation for intervention missions describes a method to communicate wirelessly with an automated underwater vehicle in a manner to provide real time control. This is done by using an onboard intelligence module and by using only limited symbolic information through the low bandwidth channel. The user only provides high level information [11].

2. Design Parameters

It is an underwater robot. The robot was designed to be underwater because the pipeline is generally 50-80% full of water. It is deployed only when a block is detected. Blocks can be detected only when no or very little water flows through them. Thus, the pipeline leading up to the block will be 100% full of water and the robot will be completely submerged. The robot is propelled by two propellers one on each side to simplify turning. The robot body is cylindrical in shape to make full use of the limited space inside the pipe. It uses an ultrasonic sensor and an infrared (IR) camera to navigate through the pipe and an IMU module to track its location. The robot must be tethered because radio and satellite and optical signals are attenuated by water. Acoustic communication is the only viable method but due to slow speed it doesn’t provide real time control. Thus, it is a Remotely Operated Vehicle (ROV).

The robot body and the end effector are made of ABS (Acrylonitrile butadiene styrene). ABS was chosen because of its impact resistance and toughness. ABS polymers are resistant to aqueous acids, alkalis, concentrated hydrochloric and phosphoric acids, alcohols and animal, vegetable and mineral oils. It is damaged by sunlight. ABS can be easily machined. It is useful in manufacturing products due to its light weight and ability to be injection molded and extruded (FDM).

The robot clears blocks by means of a robotic arm. For smooth motion of the arm it must be manufactured from metallic material and machined to high degree of smoothness. The arm is of RPR (Revolute-Prismatic-Revolute) configuration. The base revolute joint uses a stepper motor to move the end effector vertically. The prismatic joint consists of a rack and pinion actuated by a servo motor. The end effector is a rectangular base with multiple vertical fingers to distribute the force applied on the blockage. The end revolute joint is not actuated. It is simply to make the end effector parallel to the blockage when the arm moves up or down. The robot senses the block by using an ultrasonic sensor and an infrared (IR) camera. The ultrasonic sensor is calibrated to sense only the block and no other wastes floating in the pipe.

All functions are controlled by raspberry pi microcomputer. The robot clears the block by applying repeated force on it. The stepper motor moves the end effector to the top of the block. The servo motor moves the end effector to and fro, thus clearing the block from the top. Servo motor is controlled using a servo motor driver. The arm then moves down and clears the block from below. Brake discs are attached to the sides to prevent the robot body from being pushed back by the backwards force experienced according to Newton’s 3rd law. In addition to brake discs, dynamic positioning is also used. Even after the robot is anchored by the brake discs, the propellers keep on rotating in order to create a thrust that will oppose any backward forces.

Due to the block there is a build up of water pressure in the pipe. As the end effector acts on each portion of the block, the solid waste flows away with the water thus clearing the block. None of the waste form the block is collected, it is simply pushed away. The robot is designed to replace the high-water pressure hose setup and to perform the same function at a much lower cost. In the hose setup high water pressure is required because the inside of the pipe cannot be viewed. By using the camera and ultrasonic sensor the robot can act on the weakest spots of the block eliminating the requirement of large amounts of force.

2.1 Buoyancy Calculation.
Diameter and length of robot body had to be chosen such that it should be neutrally buoyant. A neutrally buoyant body neither floats nor sinks in a body of water. Instead, it floats somewhere in between.

For the robot to be neutrally buoyant the volume must be approximately equal to the weight.

i.e., 1 cm$^3$ = 1 g
or, 1 g/ 1 m$^3$ $\approx$ 1000

Assuming the total weight of the robot to be 3 kg. Total weight includes weight of body, robotic arm, propellers, dc motors, servo motor, stepper motor, motor driver, rack and pinion, raspberry pi and battery pack.

Dimensions of robot body were chosen considering pipe diameters and calculating best buoyancy by trial and error method,

Volume of main body (V) = $\pi x r^2 x h = 2733.19$ cm$^3$

Ratio of weight by volume, 3000 g/ 2733.19 cm$^3$ $\approx$ 1.098 gcm$^{-3}$

Therefore, at 3 kg of final weight, the robot is neutrally buoyant.

### 3. CAD Model

A table that displays dimensions of components in CAD Model.

| Component       | Diameter | Length | Breadth | Height |
|-----------------|----------|--------|---------|--------|
| Arm             | 60 mm    | 60 mm  | NA      | NA     |
| Revolute joint 1| 60 mm    | 100 mm | NA      | NA     |
| Prismatic joint | 52 mm    | 100 mm | NA      | NA     |
| End Effector    | NA       | 60 mm  | 60 mm   | 20 mm  |
| Body            | 150 mm   | 300 mm | NA      | 40 mm  |
| Cover           | Outer = 180 mm | 300 mm | 60 mm   | NA     |
|                 | Inner = 150 mm |        |         |        |

![Figure 1. Proposed CAD model of the blockage removal robot.](image)
4. Robot Stability
In order to make the robot stable, a fin is added to the base of the robot similar to the keel of a boat. This serves two purposes. If the robot experiences a rolling motion, the fin opposes this motion. It also lowers the center of gravity of the robot so that even if the robot rolls, it tends to straighten. Lower the center of gravity and higher the center of buoyancy, more stable a body will be. Two fins must be added below the propellers to oppose a sideward drift due to rotation of the propellers. To prevent a sideward drift, the two propellers must rotate in opposite directions, that is they must have a different pitch. This is because it is not possible to rotate both propellers at the exact same speed.

4.1 Stability Calculation.
These are the calculations done for checking whether the robot will be stable inside the water.
Volume = 2733.19 cm$^3$
Centre of gravity of main body= 75 mm (from base of body)
Centre of buoyancy = Centre of gravity because full body is submerged and symmetric.
Buoyancy = Density $\times$ 9.81 $\times$ volume = 27.47 N, (acceleration due to gravity = 9.81 m$^2$/s$^2$)
Mass displaced of body = density $\times$ volume= 3 kg
Body will be neutral equilibrium for the robot weight of 3 kg.
From the above calculations it can be said that the body will not be stable inside the water.
So, a fin must be attached below the body for increasing mass so that the center of gravity is lowered. Stability increases as the distance of center of gravity increases below the center of buoyancy.

5. Limitations and Future Scope
5.1 Limitations.
1. Robot size is such that it cannot enter the smaller and the larger pipes of diameters below 300 mm and above 600 mm.
2. Arm is not capable of horizontal motion since motion in the horizontal plane would require an additional joint which would complicate control.
3. Due to limited space hydraulic manipulator cannot be used to clear the block. Thus, the advantage of large force provided by hydraulic actuation is lost.
4. Robot cannot be used to clear smaller blocks and clogs as the water level will be low. Propellers must be completely submerged for propulsion.

5.2 Future scope
1. Robots of different sizes can be designed to operate in pipes of different ranges.
2. Additional joint can be added to provide horizontal motion.
3. Hybrid interchangeable traction can be designed for robot to operate in low water level conditions.
4. Wireless communication can be setup using acoustic modems.
5. Propeller design can be modified to prevent sludge from collecting on propeller.

6. Conclusion
Thus, a remotely operated vehicle was designed which is capable of navigating through sewer pipes. The ROV is controlled by a human operator through a data cable. It detects blockages caused by improperly disposed solid wastes using ultrasonic sensor and IR camera. A robotic arm is used to clear the block. The robot replaces manhole cleaners and expensive machinery used by government agencies to clear blocks in sewer pipelines.

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