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Development of Cleaning Device for In-pipe Robot Application

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Abstract

Pipelines are essential tools for transporting water, oils, gases and sewer from one place to another. Pipelines are used to interconnect networks from one station to another that involved various diameter sizes and fittings to compensate intended directions. There are many issues that influenced performance of the pipelines namely aging, corrosion, cracks and use to clog up with debris, or sediments after long use. There are number of methods available to clean the inside of the closed pipeline namely traditional method like boiling, picking, alcohol and salt and cleaning kits, or tools kits such as wire and plunger or large-gauge snake. However, all the methods can over-stress older pipeline and cause leaks that make even more extensive repair procedures needed to fix the problem. Chemical fluid for pipe cleaning is also not suitable to all types of pipeline because the chemical can erode the pipe wall. Currently, service robot is the best solution that purposely developed to facilitate humans being activities including cleaning, inspection for cracks or repairing damage in pipeline. This paper intends to report about the development of cleaning device for in-pipe robot application. The development covers both software and hardware of the device. Significant experiment has been designed to validate the function of the device. It is proof that the device has successfully clean the soft and moderate clog. The success of the cleaning device can be attached to the in-pipe robot and the outcome is expected to assist pipeline cleaning operations. Thus, enable the pipelines to transport efficiently with minimum cost of operation.

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*Keywords:*cleaning device; robot; pipeline; engineering design process

1. Research Background

Application of pipelines is very important in all over the world. Pipelines are used to distribute water, gas, oil or chemical fluid at certain length of distance in a closed piping system. Pipelines are also used to transport fluids within a building or between one station to another station or even thousands of distant kilometres, which is long and interconnected networks that involved various diameter sizes and fittings to compensate the intended fluid directions [1]. Due to the pipeline conditions, it is very challenging for the closed pipeline if it got blocked or even clogged that can affect its overall performance. Prior research has identified a number of causes that can influence the pipeline performance. Usually, it is not solid objects that swirl down the drain that causes a clog. The fact is that the clog is gradually built from its internal diameter. After certain period of time, the accumulated clog will reduce the pipeline diameter that consequently restricts free flow of water in the pipeline. Meanwhile, sludge is a formation of sticky concoction of soap scum, grease, hair, food particles or even the dissolved minerals in the water.

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Once the layer of sludge formed, more sludge tends to accumulate in that segment of the pipeline, increasingly narrowing the size of the pipe that will reduce the efficiency of the pipeline. At that point, even a small bit of solid flushed down the drain may instigate a total blockage [2].

Routine pipeline cleaning can be considered as preventive maintenance which is to ensure smooth pipeline operation at optimum level and also to prevent blockage by removing clog. There are a number of methods being used to clean the pipelines as summarized in Table 1. Traditional method uses boiling water, picking, alcohol and salt, and simple cleaning kits such as wire and plunge. Some chemicals also can be used like Calcium Carbide (CaC_2) and also chemicals from the acid group. However, not all types of pipeline are suitable with the chemical usage as the chemical will probably erode the pipeline. More advanced method use special devices namely Hydro-Jetting, Power-Rodding, and drain snake. The cleaning head at the end of the line integrates precision nozzles that discharge high pressure of water at approximately 3,500 psi [3]. The blast of water instantly turns sludge and clogs to a semi-solid state and flushes it away into the sewer. Meanwhile, the snake is used to drill a hole in the clog or push the clogs down then water flow may resume. Those methods work best if the blockage happened to be nearby pipe fitting or manhole as it has to be handled manually by operators. However, the methods are not suitable for industries due to safety issues and its inefficiency as sometimes the cleaning process itself can damage the pipeline. In addition, the drain snake is only suitable for small diameter pipeline use in house but not for the industrial application as the snake head is short that consequently limits its cleaning radius. Therefore, there is a strong need for the technology to assist the pipeline operation [4].

2. Development of the Cleaning Device

Development of the cleaning device has applied systematic engineering design method [5]. The development is involved with software and hardware development. Meanwhile, the movement of the robot will be controlled by Arduino software. The initial design will be based on UPVC pipeline with 300mm inner diameter since this is among the frequent pipeline size being used in domestic application [6]. Basically, there are two categories of clogs, which are soft clog and hard clog. Soft clog is due to oil and food waste. Meanwhile, hard clog is due to tough obstacles that can be from composition of mineral or incursion of tree roots into the pipeline. This research will focus on cleaning of the soft clog.

2.1. Information Gathering

Most of the related information to this research is gathered from journals, conference proceedings, and company websites. Previous researches that are related to this topic are reviewed. The information are used to get an overview of the topic so that the actual problem can be defined, some ideas and concepts from prior works are also compared.

Table 1. Summary of comparison between cleaning devices

	Advantage	Disadvantage
Power rodding	Sharp razor cuttings blades powered by high speed motor perform an efficient cleaning. Able to clean soft and hard clogs.	High rotation of sharp blade tends to damage pipe wall. Length of device is limited to few meters only. High maintenance cost
Hydro jetting	High pressure water can be considered as safer to pipe wall. Low cost.	Able to clean soft clogs only. Need to be connected with water supply thus limited to few meters.
Pipe crawler robot	Advanced technology in: navigation and tracing. Besides cleaning, it is also able to handle more complicated operations.	Complex in assembly and manufacturing. Expensive.

2.2. Concept generation

Concept development for the cleaning device is based on the functions needed. In order to clarify the cleaning device functions, there are several methods that can be used. During brainstorming sessions, the main activities of the cleaning device have been identified and summarized in Table 2. Some important functions have been identified from the activities that need to be conducted by the product. As an example, Table 2 stated that the battery needs to recharge before use and can be considered as a frequent need. The battery is the heaviest part and must be held by a stable or a strong structure placed in the housing. Therefore, it is important to highlight the needs for housing that can be assembled/ disassembled or maybe just a small access to the main housing as an entrance for the battery charger. This point should be considered from the beginning of the design process in order to avoid major changes before it reaches to the production stage.

Based on the cleaning activities in Table 2, there are a number of important functions that have been identified. The functions are summarised in Table 3. Then, the specified functions of the product can be used to generate concept design. This research emphasizes on the development of cleaning device to be used in in-pipe robot application. Same concept of grass brush cutter has been considered. Flexible cable nylon that rotates at high speed can be used to create similar cutting effect that can be used to clean the inner pipeline. Rough idea of the concepts are then matched to the appropriate components as based on its function and shown in the right column of Table 3. Some alternatives are then developed based on the cleaning device functions. The alternatives are summarised in morphological chart as shown in Table 4. Basically, it is good to have more alternatives that provide more options to consider.

Table 2. List of the main activities of the cleaning device.

Activities	Action
Setup	-Assemble the cleaning device -Set the input data -Oil the bearing -Sensor calibration
Operating	-Cleaning inside the pipeline
Maintenance	-Oil the bearing -Shaft checking -Recharge battery
Repairing	-Change The Shaft -Change the cleaning part

Table 3. List of functional decomposition of the cleaning device.

Component	Function
Sensor	To detect route by measuring gap between robot to the pipeline wall
Controller	To control the cleaning device operation
Power Source	To power all the electronic components
Motor	To rotate the cleaning part
Bearing	To take pure radial loads so that the shaft can rotate with minimum frictional force
Cleaning part	To clean the clogs/ blockage in the pipeline
Housing	To hold battery, motor, bearing and cleaning part

2.3. Analysis

Significant analyses have been performed to assess whether the development of the intended product's performance is able to meet the needed functions. Even though this process will take some time, it is safer and able to minimize failure that will consequently minimize the product's development time and cost.

Table 4. List of alternatives for sub-functions of cleaning device.

Sub- Function	Alternative				
	1	2	3	4	5
To clean	Nylon Cable	Sponge	Brush	Rubber	Fabric
To rotate	Servo-Motor	Dc Brush-Motor	Dc Geared-Motor	Stepper-Motor	-
To control	Arduino-Uno	Arduino-Uno (Bluetooth)	Remote control	-	-
To detect	Infra-Red	Touch	Laser Range	Ultrasonic	-
To minimize friction	Needle bearing	Ball-Bearing	Straight roller bearing	-	-
To power	Cell Batteries	Lithium Ion Battery	Lead Acid-Batteries	-	-
To protect	Wood	Aluminium	ABS	Steel	PVC

In order to choose the best design concept, it is important to make a correct decision. Weighted rating method offers an objective and accurate evaluation method that has been applied in this research. An appropriate weightage is given to the sub-function of the concept. More weightage is given for important sub-function that will determine performance of the designated product. Rating 1 to 5 is given for unsatisfactory performance is "0" and "5" for alternative that meet the needed sub-function. In order to clean, the concept design must be able to clean efficiently, light weight so that less torque needed to rotate, tough to ensure it not easily break during cleaning operation, flexible so that it can easily maneuver and able to clean even in narrow gap, and also low cost. Based on the named sub-functions that managed to get the highest score will be considered for a detailed design.

A detailed analysis on the mechanical elements is conducted in order to select the correct elements. The analysis covered bearing and motor selection. For instance, during motor selection it is important to know the needed torque and speed to meet sufficient cleaning requirements. As the cleaning device is designed for sewage cleaning, it is assumed that the environment in the pipeline is watery and combined with some dissolved particles that will create higher drag value. Therefore, the motor should provide enough torque to rotate in the pipeline environment. In the meantime, the speed must be high enough to create the cutting effect so that it can remove the clogs. Compatibility of the selected motor with the controller must also be checked.

At this stage, suitable material has to be considered. The main consideration for material selection of the cleaning device is density. In order to minimize the motor burden, the weight of the total design must be kept as low as possible. In order to minimize the weight, the design has to be compact, unnecessary parts has been removed and lightweight material used. In the meantime, the chosen material should have certain level of strength so that it can withstand static and dynamic loads applied. Acrylonitrile Butadine Styrene (ABS) has been chosen due to its' hardness, toughness, and electrical insulation properties. In addition, ABS has characteristic within temperature range from -20 to 80^0C. This ABS very useful because it is resistant to aqueous acids, alkalis, alcohol, animal, vegetable and mineral oil [7]. ABS can be recycled, although it is not accepted by all recycling facilities [8].

Design for manufacturing (DFM) is very critical for special purpose parts because it will determine precision of the output, thus influence the assembly process later. For more accurate and good finishing, the UP 3D printer will be used. As mentioned in section 2.2, the housing design has been divided into a number of section that can be assembled/ disassembled for maintenance and servicing process. The cleaning device has to be water proof such that the assembly has to be kept tightly to avoid electric shock during operation.

2.4. Detail design

After careful selection process, detailed analysis, watchful arrangement of elements within limited space, thorough consideration of assembly and manufacturing processes then finally detail design is produced. Based on the computer aided design (CAD) drawing, the special purpose parts are printed and assembled.

2.5. Software development

Software has been developed based on the flow of cleaning operation performed by the device. Flowchart for the cleaning operation is shown in Fig.1 and details of coding of Adruino UNO are shown in Fig.2. The programming attached is specifically for cleaning operation only and is not for the whole robot operation. The cleaning operations start when the distance detected by sensor is less than 30mm. When there is an assumed clog that narrowing the pipe diameter, motor 1, 2 and 3 will reduce speed. Simultaneously motor 4 will start the cleaning process. The process will continue until the sensor detects the distance that is greater than 30mm. Consequently, motor 4 switches off, and motor 1, 2 and 3 will increase the speed and the robot will speed up. The additional arrow defines the coding based of the flowchart.

2.6. Validation

In order to validate the design, an experiment has been designed. The aim of this experiment is to validate the functionality of the designed software and hardware of cleaning device for in-pipe robot. Three meter length of UPVC is used in this experiment. Wet and shredded tissues are measured and then glued to the inner side of the pipe. When the glue is dried, the robot will be inserted. The movement of the robot is observed and rotation of the nylon cables are measured until the robot reached the end pipe. The detached tissues from the pipe wall are measured again and compared with the initial weight. The differences determine the efficiency of the robot performance. The experiment is then repeated for other materials that represent different clogs behavior. Schematic diagram of the experiment is shown in Fig.3.

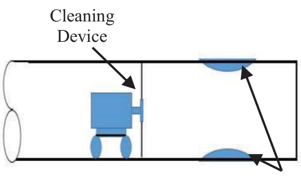

Fig.3. schematic diagram of experiment lay out

Table 5.results of experiment.

Material	Speed (RPM)	Weight $_{before}$ (gm)	Weight $_{after}$ (gm)	Efficiency (%)
Tissue	11342	200	193	96.5
	10953	200	195	97.5
	11524	200	196	98
Paper	11923	200	162	81
	11043	200	152	76
	11247	200	158	79
Plasticine	11780	240	110	45.8
	11467	240	92	38.3
	10743	240	100	41.7

3. Results and Discussion

Finally, the device that has been successfully fabricated is shown in Fig.4. The cleaning device is equipped with ultrasonic sensor that is able to detect the diameter difference. If the diameter detected is smaller than the specified dimension, the device will be defined as a blockage. Therefore, the device will start rotating until it meets the desired dimension. If the diameter is equal to or bigger than the specified dimension the device will not rotate. Observation during experiment has shown the sensor programmed is able to detect the diameter variance. Therefore, the cleaning device is able to operate automatically when needed.

Table 5 shows the efficiency of the cleaning device operation. There were three types of materials that have been used in this experiment. Each of the material represents different levels of blockage namely tissue for soft bonding clog, paper for moderate bonding and plasticine for stubborn clog. Likely, the device has performed well for the soft and moderate clog which is above 95% to 80% respectively. However, for the stubborn clog the performance has dropped tremendously. As mentioned earlier, this project is limited to clean soft clog only. Thus, the results can be considered as an initial attempt and can be used for further improvement.

4. Conclusion and Recommendations

As a conclusion, the cleaning device has been successfully developed. The device has proven to be able to clean soft to moderate level of blockage efficiently. Therefore, the device is suitable to be used for routine cleaning process. In order to improve the function of the device, there are a number of recommendations being proposed. Higher torque is needed so that the device can overcome the stubborn clog. Therefore, motor with higher than current torque and heavy duty motor can be considered. Besides that, fabrication and assembly of the device has to be improved in order to make it waterproof and robust. For the future work, the prototype performance will be compared with other established products.

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Fig.2. specific coding for cleaning operation.

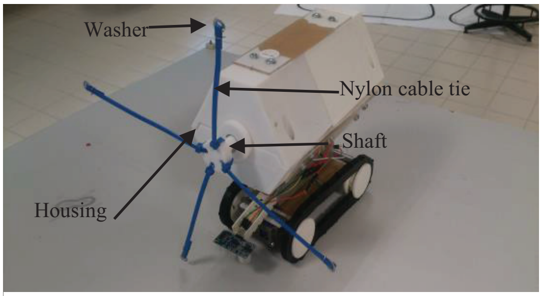

Fig.4. Prototype of cleaning device attached to the robot.

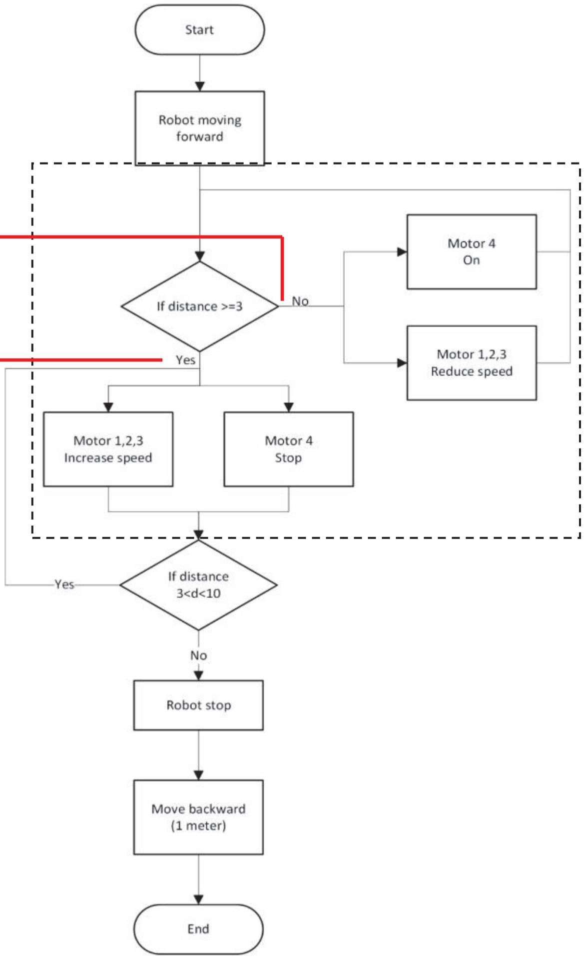

Fig.1. flowchart for cleaning operation.