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Design and Development of a Reconfigurable Type Autonomous Sewage Cleaning Mobile Manipulator

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Abstract

The advances in robotics, in the last ten years, have enabled robot technology to solve many practical problems that humans encounter in day-to-day activities. But, even today manual scavenging of the sewage is practiced in urban areas of India, wherein man enter the manholes and clean the scales and clogs in the sewage pipelines manually with virtually no technical equipment. This practice might jeopardize the lives of humans; therefore, a sewage cleaning robot is essential to replace the human intervention. The conventional sewage cleaning robots available are not capable and effective in cleaning a variable diameter pipelines. In order to overcome this issue, an attempt has been is made to design and develop a reconfigurable type sewage cleaning mobile manipulator, which can efficiently clean the scales and clogs formed in the variable diameter sewage pipeline. A conceptual model of the manipulator has been created in solid model using solid works. It will give a clear understanding of the manipulator and its subsystem interactions. A prototype model of the manipulator has been developed based on the design concept and its working environment i. e, various goals that robot has to do after entering the sewage pipe and hence the functional requirements are finalized. It consists of various links and joints. The joints are drive through the various motors which are discussed in the paper. Preliminary investigations are carried out on the developed prototype model and some of the results are discussed in the paper.

Keywords: Robotics, Mobile manipulator, Solid modelling, Periodic maintenance

1. Introduction

For a long time, robotics has been the domain of universities, industrial laboratories and car-production lines.

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Nomenclature

HC	High Cut-off
LC	Low Cut-off
L	Distance between infrared sensor and traction wheel
MLS	Manipulator Limit Switch
T	Reconfiguration time, s
E_R	Energy consumed by Reconfiguration Motor
Subscripts	
IR	Infrared
SET	Set value reference voltage, volts

The robots were usually large, slow and incredibly specialized manipulator arms anchored to the assembly-line floor. Fortunately, the advances in robotics have enabled robot technology to come out of the laboratory into the garage of the interested builder. Microprocessors have become cheaper and more powerful, motors are smaller and stronger and knowledge is a plenty and easier to access. This ensured that the concept of using robots came out of the realm of the virtual world for the betterment of human's life in day-to-day activities to carry out dirty, dangerous and dull jobs like sewage cleaning, nuclear power-plant inspection etc.. Most of the municipalities in the world run sewers. The standards of sewage treatment and, consequently, the sizes of sewers differ, but the length and cross sectional areas of sewage pipeline vary greatly in different countries. Total sewer pipe length in Japan, e.g., was 250,000 km by the end of 1994 [1] and in Germany were about 400,000 km in length in 1997 [2]. If designed, built, and used properly, a sewer may just work for a long time. About 31.4% of the communal sewers in West Germany were 50 years and older. However, it is mandatory to put effort into sewer maintenance to guarantee proper function, to protect the large investment capital spent to build them, and to prevent damage from the sewer itself, from sewage treatment plants, and from the environment. Blockage in sewage pipeline is a tedious job, wherein, human interference in not advisable. Sewer pipelines in India are usually existed from 200 to 2000 mm in diameter for sewer transmission from houses to refineries. In the past, pipes were manufactured from concrete but recently the polyethylene type pipelines are more commonly used for the sewage collection [3-5]. However, the material of the pipes affect the kind of problems occurred in the system. Some of the problems may happen in sewer network are:

- Clog and scale formation.
- Settling of waste materials like tree branches, plastic containers.
- Distraction of pipes in joints and corrosion of pipe surface.
- Deformation of pipe and change in cross section.

The above mentioned problems could block the sewage pipeline and hence, periodical maintenance is an essential procedure. In addition to this, existence of small diameter pipes, unsuitable environment of sewer pipes and the necessity of cleaning, force the application of a robot for the sewage cleaning. Larger pipes, i.e., those wider than 180 cm inner diameter, are considered accessible for humans and can be cleaned by conventional procedures. But, only relatively few mains are accessible, the vast majority of sewer pipes is not, diameters going down to 15±10 cm towards inlets from single houses [6]. Typically, inaccessible sewers are cleaned by conventional procedure like using a cleaning stick which is inefficient and slow procedure. To overcome these issues, a mobile manipulator robot type sewage cleaning mechanism should be developed. Generally, mobile robots have the capability to move around in their environment and are not fixed to one physical location. In contrast, industrial robots usually consist of a jointed arm (multi-linked manipulator) and gripper assembly (or end effecter) that is attached to a fixed surface. Mobile robots are the focus of a great deal of current research and almost every major university has one or more labs that focus on mobile robot research. Mobile robots are also found in industry, military and security environments. They also appear as consumer products, for entertainment or to perform certain

tasks like vacuum. A mobile manipulation system is a hybrid version of mobile robot and a serial or a parallel manipulator, which offers a dual advantage of mobility offered by a mobile platform and dexterity offered by the manipulator. The mobile platform offers unlimited workspace to the manipulator. The extra degrees of freedom of the mobile platform also provide user with more choices. However the operation of such a system is challenging because of the many degrees of freedom and it performs in the unstructured environment.
General system consists of:

1. Mobile platform
2. Links and Joints
3. End effector
4. Vision- for detection of clogs and scales
5. Tooling- to crush the clogs and scales

At the moment mobile manipulation is a subject of major focus in development and research environments, and mobile manipulators, either autonomous or tele-operated, are used in many different areas, e.g. space exploration, military operations, home-care and health-care. However, within the industrial field the implementation of mobile manipulators has been limited, although the needs for intelligent and flexible automation are present. In addition, the necessary technology entities (mobile platforms, robot manipulators, vision and tooling) are, to a large extent, available off-the-shelf components.

The simple mechanisms can permit movement only in horizontal pipes [7-9]. Although they have the difficulty of producing necessary friction force to continue moving in far distances to pull extensive lengths of their power and signal cables, the traversing mechanisms are much simpler. However, many original locomotion concepts have been proposed to solve the numerous technical difficulties associated with the changes in the pipe diameters, presence of vertical pipes, various elbow and providing the necessary energy supply [10]. Walking mechanisms offer complex discrete, rather than simple continuous pipe wall contact for movement. Consequently these mechanisms have not been used in the sewage cleaning pipes. Hence, a mechanism's which can handle all the situations and conditions discussed in the paragraphs should be designed and developed, which becomes the most essential engineering in the world.

1.1. Need for recognition

In our day-to-day activities, the robot technology has facilitated to solve many practical problems. However, even today in India, men enter the sewage pipeline to clean the blocked sewer manually. Figure 1 shows the variable diameter sewage pipeline with scales and clogs, which restrict the motion of sewage.

Fig.1 Sewage Pipe with Clogs and Scales

The poisonous gas from the sewage and sewage blockage would jeopardize the life of the human who enter the manholes. It is also difficult for a human to clean a variable cross sectional area pipeline. So it is imperative that manual cleaning of sewage should be replaced by a robot mechanism which can reconfigure to variable pipe diameters. From extreme field study about the sewage pipeline; it was apparent from the study that a reconfigurable type mechanism is required to adapt to different cross sectional area of sewage pipeline. In this paper, an attempt is made to avoid human effort for cleaning the variable diameter sewage pipelines. Hence a prototype of reconfigurable type sewage cleaning robot has been designed and developed with a manipulator to clean the scales/clogs efficiently. Preliminary investigations are also carried out to characterize the robot and its motion.

2. Development of a sewage cleaning robot

A conceptual design was finalized considering the various goals that manipulator can do after entering the sewer pipe. The solid modeling of the various components and their assembly for conceptualization is carried out using the solid works. Fig. 2 show the solid model of the manipulator which consists mainly reconfigurable movable disk with various associated links and joints, central threaded shaft drive through high torque DC motor and end effector, A prototype of the model (Fig. 5) has been fabricated using proper selection of various components- manipulator motor, movable reconfigurable disc, reconfigurable links, idle wheels and traction wheel, infra red transreceiver, control and driver circuits and power pack. The selection of the various components is based on the low cost and easy controllability. The prototype will be remotely controlled mobile robot moving on a smooth ground that shall crush simple obstructions which come along is path. The intent would be to justify the verity proposed mechanism. The cleaning of sewer is the most essential design aspect and effectiveness of this function is the highest priority. There are three methods which can be considered as given below:

- The robot head has a pneumatic cylinder which can push the clog forward
- Drill bit and saw tooth bits can be used to disentangle the clog and clot
- Pressured water jet can also be used to flush the clogs.

These are three methods push out the clog into the sewer pipe. To overcome this, the manipulator can be made to collect the sewer instead of pushing it along the pipe. But collecting the sewer would be cumbersome as the manipulator will have to sense the amount of clog, and also make numerous to-and-fro motions until the clogged sewer is completely collected.

Implementation of this method becomes more difficult. To reduce the probability of re-accumulation of sewer, it is important that the sewer is disentangled and loosened using cutters like saw-tooth bits or drill bits. A clogged pipe line already contains sewage water on one end, because the sewage water can unable to pass the obstacle. So if the robot can crush the clog, then the sewage water can flush the away acting as pressure water jet. Thus a large cutter will be used to penetrate into the clog and crush it. Sewage water will then act as a flush to carry the loosened clog along with it.

Figure 3 shows the schematic diagram of a reconfigurable type sewage cleaning robot. It consist of sub-system such as manipulator, reconfigurable mechanism, Infra-Red (IR) transmitter and receiver - proximity sensor, manipulator motor, traction motor, battery power-pack, limit sensor, microcontroller, signal processing and H bridge circuits

The manipulator of the sewage cleaning robot is specially designed for the cleaning the scale and clogs effectively. A nut and screw based reconfigurable mechanism is designed with three link pair attached at 120 degree orientation as shown in Fig. 2. This reconfigurable mechanism is powered by a high torque DC motor and is used to position the robot in variable cross sections of the sewage pipeline. An H bridge is built with four switches (solid-state or mechanical). When the switches S1 and S4 (according to the first figure) are closed (and S2 and S3 are open) a positive voltage will be applied across the motor. By opening S1 and S4 switches and closing S2 and S3 switches, this voltage is reversed, allowing reverse operation of the motor.

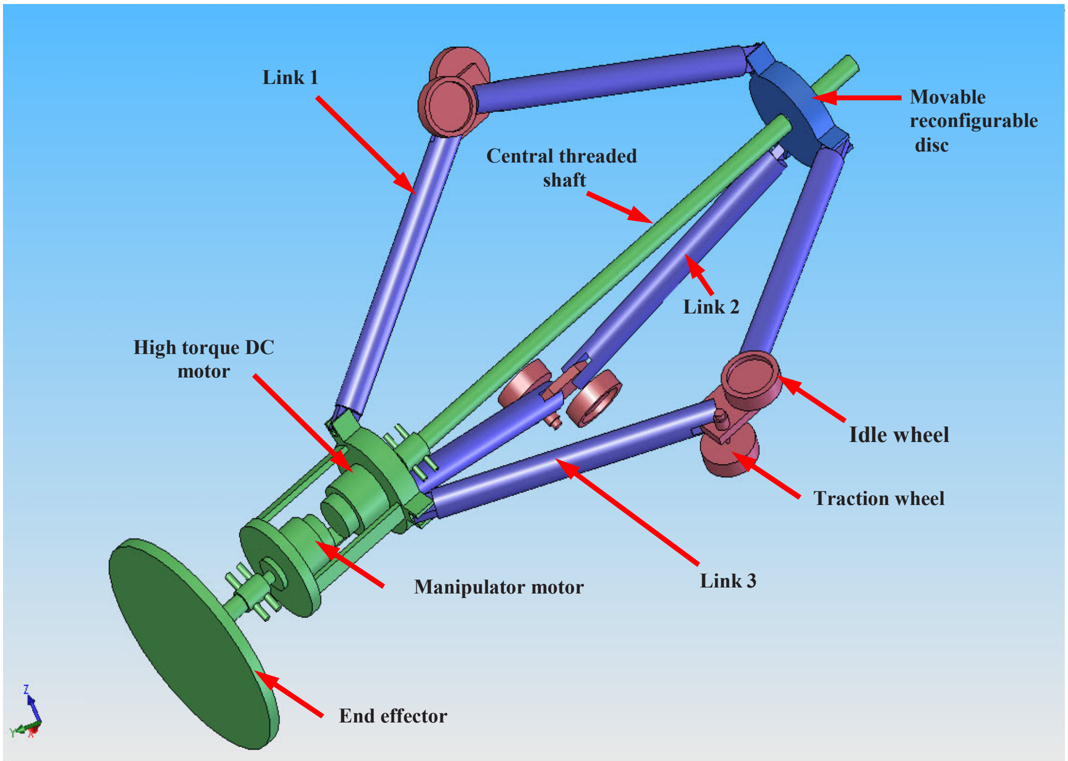

Fig.2 Solid Model of the Sewage Cleaning Mobile Manipulator

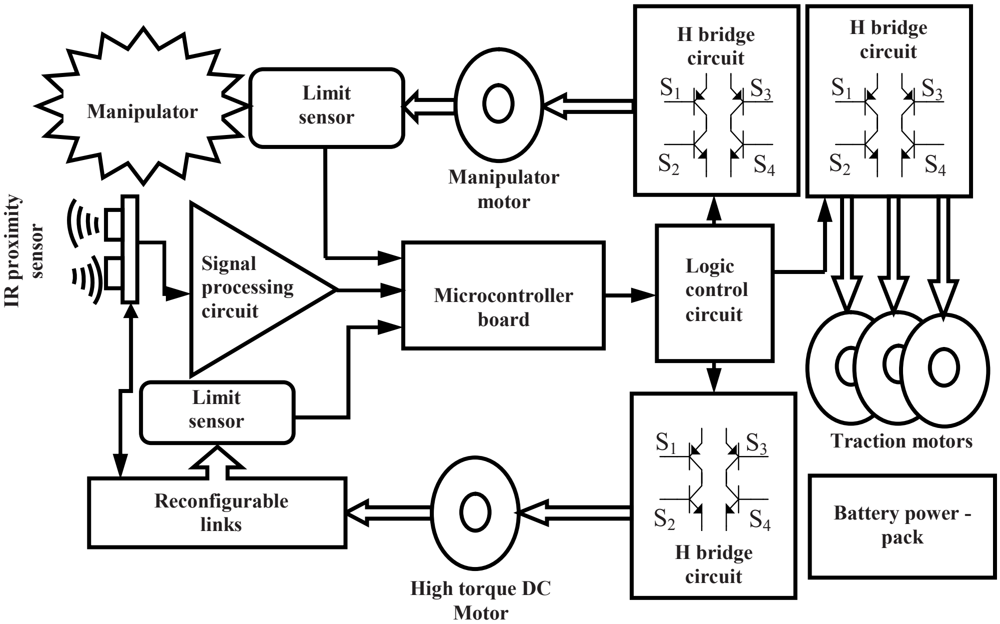

Fig.3 Schematic of the reconfigurable sewage cleaning robot

Using the nomenclature above, the switches S1 and S2 should never be closed at the same time, as this would cause a short circuit on the input voltage source. The same applies to the switches S3 and S4. This condition is known as shoot-through. The H-bridge arrangement is generally used to reverse the polarity of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit.

The working principle of reconfiguration type sewage cleaning mobile manipulator is as shown in Fig.4. The InfraRed (IR) proximity sensor mounted on the reconfigurable link is used to determine the diameter of the mobile manipulator robot. The feedback voltage signal (V_{IR}) generated from the IR proximity sensor is amplified and compared with reference voltage set value V_{SET}. If the V_{IR} voltage magnitude is more than V_{SET} value then reconfiguration motor is switched OFF and traction motor is ON and manipulator motor also switched ON. The direction (clockwise and anticlockwise) of rotation of traction motor is determined by the states of the manipulator limit switch. During the forward motion of robot, the traction motor is in clockwise direction but, when the manipulator is stalled due to extra loading effect by extreme blockage of sewage then the manipulator limit switch is activated.

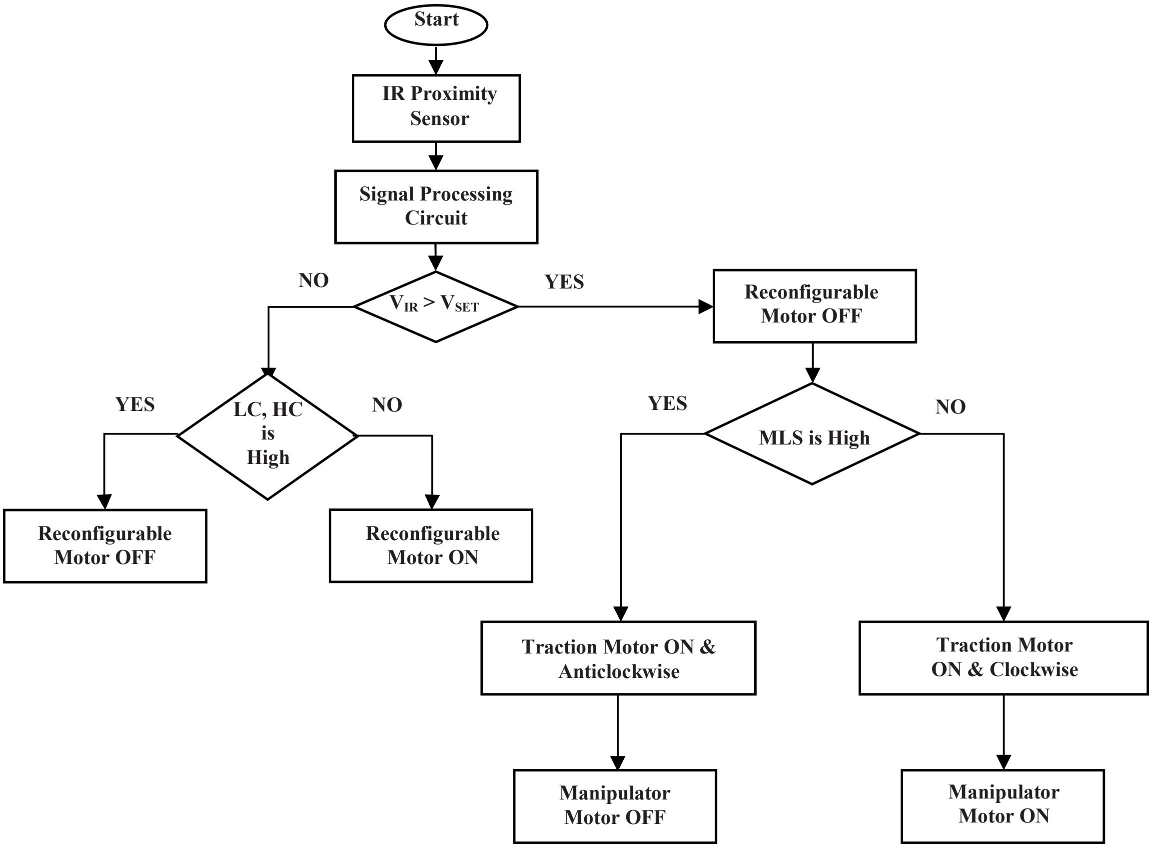

Fig. 4 Logic adapted in reconfigurable sewage cleaning robot

The controller commands the traction motor to run anticlockwise, So that the mobile manipulator robot takes a replace path. In the other case, if the V_{IR} voltage magnitude is less than V_{SET} value then reconfigurable motor is ON. But, when it is higher cut-off (HC-0.5 meter) and lower cut-off (LC- 0.3 meter) limit switch is activated, which automatically switches OFF the reconfigurable motor.

3. Experimental characterization of a reconfigurable type sewage cleaning robot

Characterization of a reconfigurable type sewage-cleaning robot involves the study of dynamic characteristics of reconfiguration displacement for a given input power in the reconfigurable motor. Figure 5 shows the experimental setup of a reconfigurable sewage-cleaning robot along with controller and driver circuit.

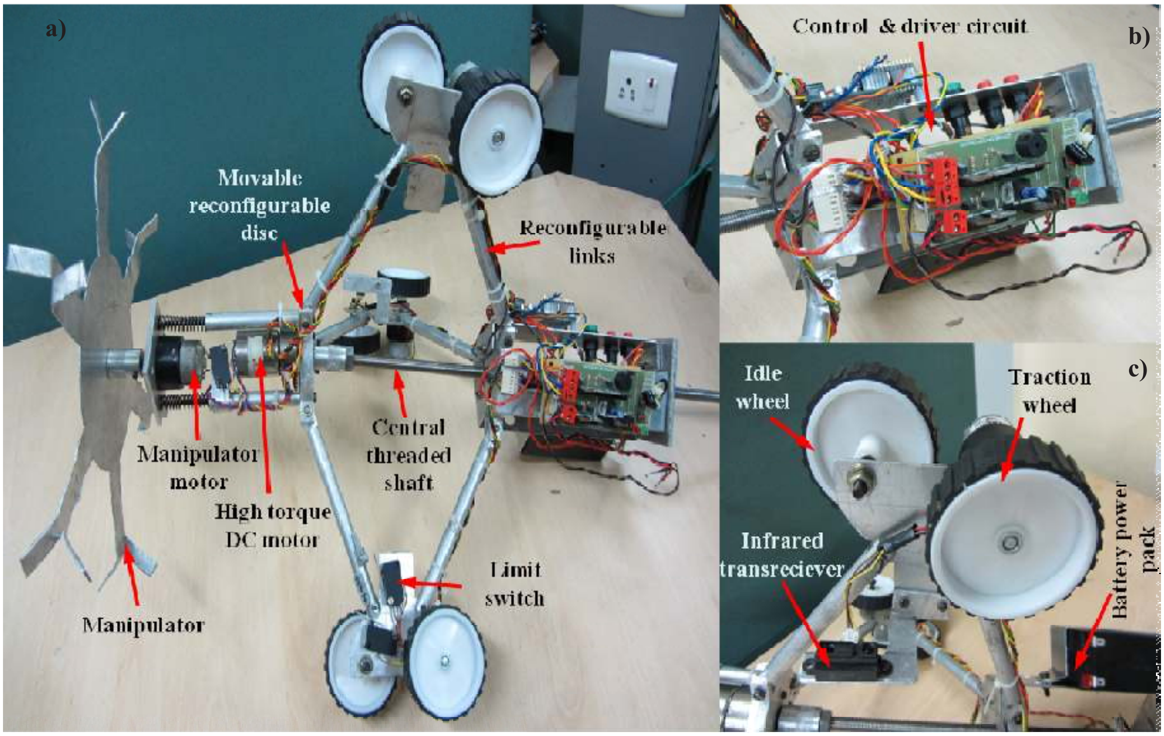

Fig. 5 Experimental setup of a reconfigurable sewage cleaning mobile manipulator

The IR transreceiver is mounted at a distance (L_{IR}) of 0.11m from the end of the traction wheel, which makes the contact with the pipeline. The distance L_{IR} is calibrated based on the standard calibration charts of the (GP2D12) IR sensor. The robot system is switched ON and a constant speed of 10 rpm is maintained at the reconfiguration motor to study the dynamic characteristic of reconfiguration links. The IR sensor displacement is recorded and plotted as shown in Fig 6 (a). It was observed that, the reconfiguration link displacement varies with respect to time. The lower limit of the reconfiguration has a physical limit of 0.3 meter at a initial condition of complete expansion of the linkage. After a complete retraction of the reconfiguration links, it was found that the effective reconfiguration is possible up to a limit of 0.5 meter with a expansion range of 0.2 meter.

Fig 6(b) shows the reconfiguration motion along the links 1, 2 and 3 respectively. It is evident from the plot that, the reconfigurable motion by this mechanism provides a triangular workspace with an area of 0.013 m^2.

The motor current consumption for the total reconfiguration is recorded and plotted as shown in fig 7 (a). A constant speed of 10 rpm is maintained by supplying a constant voltage of 12 Volt as shown in 7(b).It is observed from the motor current consumption that, the current varies according to the load applied (or) resistance offered by the links in the reconfiguration.

Sizing of battery is based on the total energy consumed by the system for the given load. Total energy consumed by system is equivalent to the energy consumed by traction motor, reconfigurable motor and manipulator motor. Figure 8 shows the power consumption of the motor during the reconfiguration.

The energy required for the reconfiguration is calculated from the area under the curve of motor power consumption with respect to time. The total energy consumed [E_R] for reconfiguration from the battery is shown in Eq.1.

$$E_R = \int_0^T P \, .dt \tag{1}$$

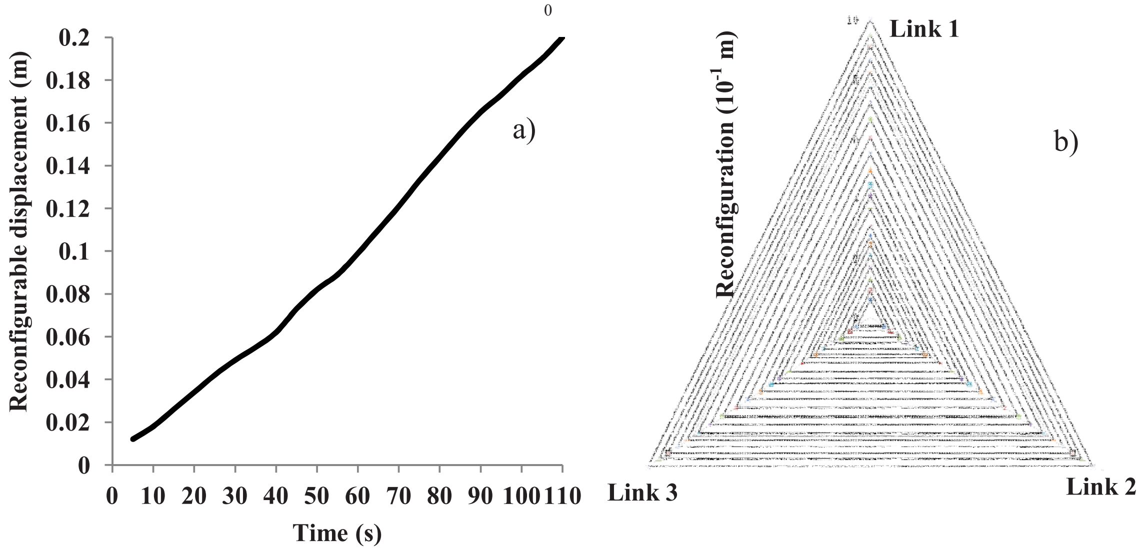

Fig. 6. (a) Reconfigurable displacement vs. time; (b) Reconfiguration along each link

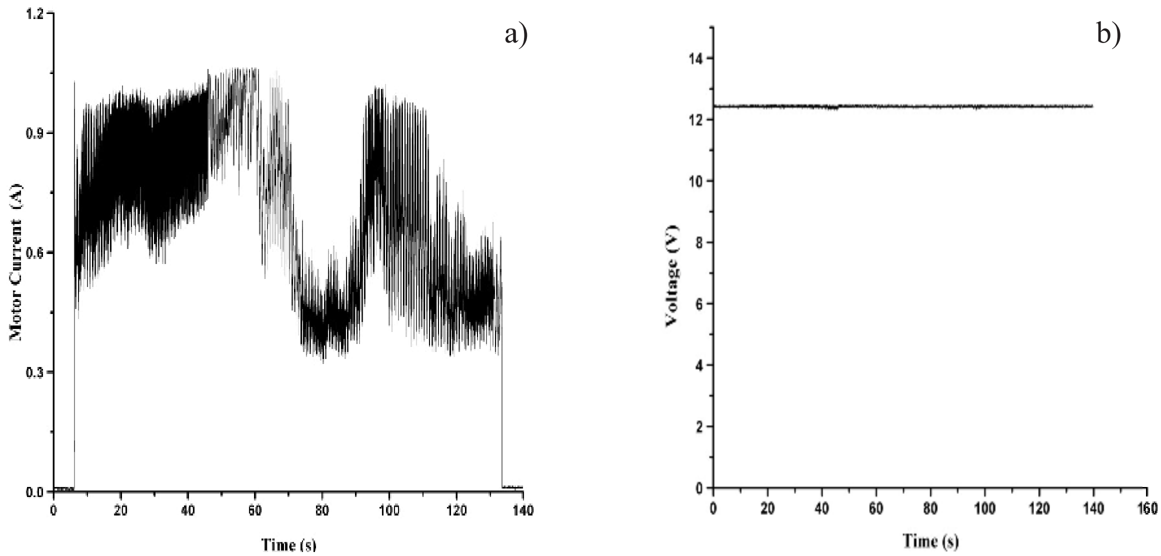

Fig. 7. (a) Motor current vs reconfiguration time; (b) Motor voltage vs reconfiguration time

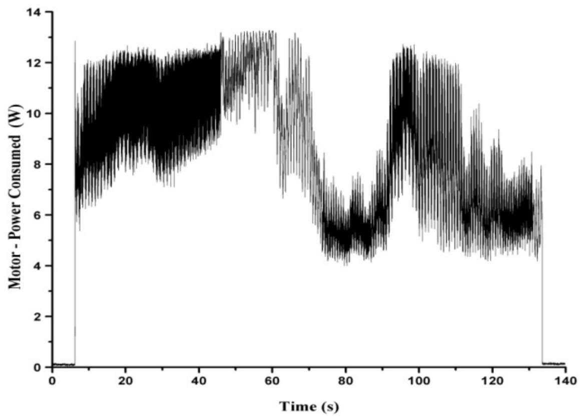

Fig. 8 Motor -power consumed vs reconfiguration time

Total energy consumed by the traction motor, manipulator motor and reconfigurable motor are shown in Table 1. The standard battery available can deliver 12 volt and 1.2 ampere for an hour. Hence, this battery can deliver 14.4 Watt-hour which is approximately equal to the total energy consumed.

Table 1. Energy consumed by the system

Actuators	Power consumed (Watt)	Total time period of operation (hour)	Energy consumed (Watt-hour)
High torque DC motor	0.3	(1/60)	0.01
Manipulator motor	1.375	(5/2)	3.44
Traction motor	4.13	(5/2)	10.33
		Total energy consumed	13.78

Conclusion

- Robots are generally used for industrial, domestic and military applications. However, dirty, dull and dangerous jobs like sewage cleaning should be handled by robots. Although, commercial sewage cleaning robots are available, cleaning the variable diameter or cross sectional area sewage pipeline is cumbersome.
- In order to overcome this practical difficulty, a reconfigurable type sewage cleaning robot mechanism was developed, which can reconfigure its own body to variable diameter sewage pipeline.
- A prototype of mechanism with a reconfiguration range of 0.3 to 0.5 meters was developed for an experimental investigation.
- Characterisation of a reconfigurable sewage cleaning robot was carried out.
- Dynamic characteristic curve of reconfiguration shows a triangular workspace area of 0.013 m^3. Total energy of 13.78 Watt-hour consumed by the system is calculated from energy consumed by the loads - traction motor, manipulator motor and reconfigurable motor.
- From the total energy calculated, the standard battery size is determined as 12 V and 1.2 A-hour.

References

[1] Fukui, T. (October 1994). Current status of non-digging techniques applied to sewerage work in Japan. In fourth international conference on pipeline construction, volume Japanese Forum (pp. 1-14), Hamburg, Germany, 16-20.

[2] Dyk, C., & Lohaus, J. (1998). Der Zustand der oentlichen Kanalisation in der Bundesrepublik Deutschland. Ergebnisse der ATVUmfrage 1997, ATV-Information (24p). Hennef, Germany: ATV (German Association for the Water Environment.

[3] H. Roth, K. Schiling, S. Futterknecht, U. Weigele, M. Risch, Inspection and repair robots for waste water pipes, a challenge to sensories and locomotion, Proc. of IEEE International Conference on Robotics and Automation, pp. 476-478, 1998.

[4] K. Suzumori, T. Miyagawa, M. Kimura, and Y. Hasegawa, Micro Inspection Robot for 1-in Pipes, IEEE/ASME transactions on mechatronics, Vol. 4, No. 3, 1999.

[5] S.G. Roh, S.M. Ryew, J.H. Yang, H.R. Choi (2001), Actively steerable in pipe inspection robots for underground urban gas pipelines, Proceedings of the IEEE International Conference on Robotics & Automation, Korea.

[6] Kirchner, F., & Hertzberg, J. (1997). A prototype study of an autonomous robot platform for sewerage system maintenance, Journal of Autonomous Robots 4, 319-331.

[7] Hertzberg, J., & Kirchner, F. (1996). Landmark-based autonomous navigation in sewerage pipes. In Proceedings of the first euro micro workshop on advanced mobile robots (EUROBOT '96) (pp. 68-73), Los Alamitos, CA: IEEE, Kaiserslautern, Germany, 9±11 October, 1996.

[8] Cordes, S., Berns, K., Eberl, M., Ilg, W., & Suna, R. (1997), Autonomous sewer inspection with a wheeled multi-articulated robot, Robotics and Autonomous Systems, 21, pp 123-135.

[9] W. Ilg, K. Berns, S. Cordes, M. Eberl, R. Dillmann (1997), A wheeled multi joint robot for autonomous sewer inspection, Proceedings of the IEEE international conference on robotics & automation, pp.1678-1692.

[10] M. Moghaddam, A. Hadi, T. Abbasian, (October 2007) "Design and Manufacturing SEWBOT: a Sewer Inspection Robot", 1st International Conference on Technical Inspection and NDT, Tehran, Iran.