Pipe Leakage Repairing Robot

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August 28, 2013
Executive Summary

This report summarizes research on offering a solution for an auto-repairing process for leakages inside a pipe network. This solution is an extended phase of the “In-pipe leak detection sensing” project [1] that can detect leakages inside the pipe network. Several manual processes were viewed as well as similar existing projects and products. Deployment mechanism and the design of the robot that will handle the repairing process are discussed briefly for a first draft version of it. A comparison between two types of repairing kits was listed to show the optimum selection. The result of the repairing pipe leakages experiments emphasize that the project can succeed and can be also further developed in the future. The study also investigates some future improvements that can be applied to have an enhanced version of the repairing robot.
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1 Introduction:

1.1 Overview
All pipe networks may face leakages and some of these leakage situations can lead to injuries, financial and human losses, and sometime to real disasters. The severity of the losses and damages will depend on the type of material being transported inside the pipe and also the size of the leak.

1.2 Problem Definition
- In case of a water pipeline leakage, this will lead to a loss of a valuable resource.
- In case of gas leakage, this will endanger lives and will lead to respiratory problems.
- In case of oil or any oil derivative leakage, this will lead to a drain of un-renewable resources.
- Underground pipes cannot be reached and therefore are difficult to repair.

1.3 Project Objectives
- Avoid any losses or any problems while transferring material inside pipes.
- Avoid replacing the pipe.
- Reducing the cost of the repairing process.
- Reduce the time of the repairing process.
- Reduce human effort and risks.

1.4 Project Features
To be able to reach the project’s objectives, a robot has been constructed and equipped with some tools to be able to fix the leakage inside the pipe network. The deployment mechanism will be as follows:

The cart will go to the detected leakage area and then rotate the nozzle to the correct circumferential position and then the servo will spray the adhesive on the affected area. The nozzle will be able to swing so that the spray can cover the hole of the detected leakage and its surrounding area.

This is a result of two reasons, first is that some leakage is presented as cracks and this operation is to guarantee that all potential damaged area will be repaired. The second reason is that some leakage cases are presented as a large hole and by this swinging operation it will guarantee that the hole will be filled and the surrounding area is covered as well to make sure that it will not move and cure in the right position.
2 Backgrounds:

2.1 Leakage Situations:
Oil, Gas, and water leakage incidents are mentioned in the points below as well as the different measures taken to repair these leakages.

- Oil pipeline leak repair under way:
  The article mentioned in the Royal Dutch Shell website [2] describes an oil pipeline leakage in Dyersburg, Tennessee and how it was fixed. The leakage was found around 6 pm on Saturday April 12, 2008, which was the size of a dime. The incident commander in Royal Dutch/Shell Oil Co. Gary Stovall announced that the leakage was noticed by a routine inspection revealing 10 gallons of oil was leaked on Friday around 2 pm on the north side of State Highway 104. The pipeline sizing 40 inches in diameter carries a million gallons of petroleum from offshore rigs in the Gulf of Mexico to the company’s terminus about 60 miles east of St. Louis, MO. The fixing of the pipe started immediately after finding the leakage, the inch thick casing of the pipe was cut and a replacement casing was brought in addition to the welding and X-Ray workers who will attach it on Sunday. The mentioned pipeline was the largest diameter pipeline in the U.S. since 1963, until the 48-inch Alaskan pipeline was constructed. The same pipeline leaked in 1999 on Highway 77 east of Newbern resulting in the loss of 90 barrels of crude oil as well as property damage, including a section of the state highway which needed to be rebuilt, as reported by the U.S. Department of Transportation’s Office of Pipeline Safety, costing Shell $1.665 million.

- Kuwait Gas Leak Puts 4 in hospital:
  ARAB TIMES [3] published that on Wednesday October 17th, 2012, a gas leakage in the well #136 in Al-Rawdhatain oilfield in Northern Kuwait led to at least four casualties and a strong odor of rotten eggs, indicating the presence of hydrogen sulfide in the air. Kuwait Oil Company said the spill resulted from the explosion of one of the pipes while the Burgan Company for Drilling Wells was carrying out a drill operation on well #136. They indicated that the work at the Gas Assembling Center in Al-Rawdhatain field was immediately suspended and laborers were evacuated. When the concerned authorities were unable to control the spill, they burned the gas leaking from the well to reduce the amount in the air and the firefighting department of the Kuwaiti army intervened and managed to control it by 10 pm on Wednesday. Areas near Al-Rawdhatain oilfield were evacuated and people were advised to stay indoors.

- Arizona Central: Call 12: Student hit with $16,000 water bill:
  A Northern Arizona University nursing student was in debt from a $16,349.57 water bill. The total water use was more than 1 million gallons which would fill about 80 average-sized family swimming pools. The student, Rob Peer, thought he could never have used that much water at his home that he rented near campus. Rob contacted his mother Christine Peer who contacted Call 12 for Action of NBC in Richmond, VA. The plumbers found a leak that caused the extravagant bill. The rental it turns out experienced a broken pipe in late February. The pipe leaked more than 1.5 million gallons into the ground until it was discovered. The mayor of the city of Flagstaff, Jerry Nabours whose office had taken interest in the case described the process to recover the $16,000 as “ongoing,” saying that the property owner and the city are negotiating a settlement [4].
2.2 Manually Repairing Process:
In general, there are some popular and common ways to repair the leakage in the pipe network. For the copper pipe, Family handyman website [5] provided an efficient step-by-step way to fixing a leaking copper pipe at home with special repair sleeves. The first step is to cut the damaged pipe after shutting off the main water valve. After that the pipe is cleaned of corrosion in preparation for the sleeve installation. Then the repair sleeve is slid in the damaged pipe and centered so ½ an inch is inside the copper pipe. The final step is to solder the pipes together using a torch flame and solder. The directions are given for different sizes of pipes such as ½” and ¾” copper pipes as well as helpful hints to perfect the fixing procedure.

City of Puyallup website [6] is another website that mentions how to detect and fix leakages. The website states several tips on fixing leakages by the homeowner:

- Begin by turning off the main water in the house
- After detecting the leaking pipe, clear the area and clean the pipe
- If the leakage is from a joined area, then undo the join and clean it, and before rejoining it repair with plumber’s tape around the seal.
- If the leakage was from cracks or holes in metal or plastic pipes, the damage can be sealed by purchasing and installing the correct putty or sealant and tape from the hardware supplier.

“Do it yourself: How to Repair a Gas Line Leak” is an article[7] that mentions in simple steps the process of repairing a gas line leakage that might result from a tear, or scratch from high pressure in the pipe. The following are the steps to repair a gas line leak:

- Step 1: Turn off the Gas.
- Step 2: Remove the Covers.
- Step 3: Detach the Gas Line.
- Step 4: Remove The Residue Gas Pressure.
- Step 5: Clean the Line.
- Step 6: Scuff The Surface.
- Step 7: Attach The Gas Line.
- Step 8: Apply the Epoxy.
- Step 9: Test the Gas Lines.
- Step 10: Reinstall The Covers.
2.3 Repairing Kits:
Moreover, there are many websites and stores that sell several types of repairing kits. One of these websites is Pipe Wrap Leak Repair [8]. This website offers many products to fix different pipe leakages whether it’s water leakage or corrosive chemical leakages. Products that are mentioned are as follows:

- **Pipe Wrap**: A resin-impregnated fiberglass that adheres to PVC, fiberglass, concrete, and all metal pipes. It’s cost effective, durable, and easy to use.
- **EPRK**: An all-inclusive Emergency Pipe Repair Kit (EPRK) that is easy to use for temporary leakages, stopping active leakages up to 300 psi and can be installed in 15 minutes.
- **RidgeBack**: Provides a concentrated clamping force to stop active leaks up to 150 psi and is suitable for chemical leakages and can stand temperatures up to 250°F.
- **ALRK**: Active Leak Repair Kit (ALRK) is a compression sealing system for low-pressure, active leaks up to 75 psi.
- **LeakStop**: A clamp to stop all active leaks up to 100 psi and is suitable for chemical handling and withstands temperatures of up to 250°F.
- **Pipe Wrap Residential**: Similar to the industrial leak repair system and comes in easy to use DIY kit.

“Indumar Pipe Leak Products” is another website [9] that offers several products to repair pipe leaks. Some of these products are:

- **Stop It Pipe Repair System**: Repairs cracks and leaks in Carbon steel, stainless, aluminum, copper, galvanized; PVC, CPVC, PVDF, polyethylene, polypropylene and fiberglass pipes. It’s a knitted fiberglass tape coated with special urethane resins that are water-activated which makes this product suitable for underwater repairs. It is a hand-applied product and doesn’t need any tools or soldering to be used, it takes approximately 30 minutes to cure.
- **Stop It HP, High Pressure Leak Sealant Technology**: This product is designed to work with pressures up to 2000 psi. Before applying Stop It HP, the surface has to be prepared by removing any loose scale and any lubricants or greases as well as reducing the pressure in the pipe and the temperature of the surface should be not less than 50°F and not greater than 100°F. After preparing the surface to be repaired, the product can be applied by mixing a premeasured two-part sealant, wetting a fibrous reinforcement tape, and wrapping the tape on to the pipe surface.
- **First Response Leak Repair Kit**: This kit provides items to make it possible for repair teams to quickly fix leaks, cracks, and gashes in pipes, tanks, and drums in the case of emergencies.
- **Fix Stix**: This handy, simple-to-use product can be used to stop leaks, fill holes and cracks and can also be used as an adhesive and it takes 20 minutes only to become solid. This product is hand moldable, water resistant, works over a wide temperature range, and has chemical resistance.
- **Fusion Tape**: This tape is easy to use and can be used for all purposes, it won’t crack or separate with sudden shock or vibration, expansion or contraction. It has a dielectric strength of 400 volts/mil. Fusion Tape works over a wide range of temperatures and it can be used as primary cable insulation for Class H temperatures (180°C/356°F). The product is also resistant to moisture and ozone which makes it preferable for environmental insulation.
2.4 Advance Repairing Kits:
Advanced Repairing Kits can be used for leakages that are more complicated. The following are some of the advanced repairing kits used:

1) Link-Pipe Pressure Seal[9]:
   This product is an internal repair sleeve designed for pressure pipe joint and pin-hole repair. The Pressure Seal uses mechanically locked stainless steel combined with resin sealer to produce a long-term seal. The Pressure Seal can seal pipes with pressure up to 150 psi and is suitable for old cast iron mains that have unpredictable variations in manufacturing tolerances, roundness, and joint offsets where the sleeve would fit.

2) Residential Plumbing Services, Non-Destructive Trenchless Pipe Repair[10]:
   The products described in the website use a nondestructive, no excavation or restoration methods to repair leaking pipes. The company, Trenchless Technology, has created a product called Cured-In-Place Pipe (CIPP) in which a pipe is created within the existing pipe using special epoxy resins to make the structural strength of new pipes without damages to structures, floors or landscaping. Accurate Leak & Line technology uses a pull-in-place (PIP) method where the liner is pulled into position where needed and is filled with epoxy and cured into place. The advantage of using this product is that the epoxy is placed only in the needed areas in the pipe which means significant cost savings and flexibility in repairing.

2.5 Survey
After viewing the several manual repairing methods and the repairing kits, it’s clear that even though they have easy steps they require effort to do it. Some situations may require time to cover all the leakage, or may call for an experienced person to repair the leakage. Most importantly, there is a risk in the manual repairing process as well as using the repairing kits. In fact, all these factors may exist in one leakage situation, requiring effort, time, and experience.
2.6 Local Company or Product:
The following are local companies or products that tried to tackle the problem of leakages using robots:

1. A Robotic System to Locate Hazardous Chemical Leaks:
The paper [12] discusses using low cost, simple, autonomous robots to detect chemical leaks. There will be several robots used to detect the chemical leaks which would improve reliability through redundancy and will provide larger area coverage. Sensing and control techniques to detect the location of leaks are mentioned in the paper as well as the algorithms used to develop it.

2. Innovation on NBC NEWS, Robots to help repair aging water pipes:
The article [13] by Dan Hope[11] describes an initiative to build robots that can access and repair aging water pipes from the inside. The article mentions that the American Society of Civil Engineers estimates that 6 billion gallons of clean drinking water disappears each day because of old leaky pipes and mains in many cities throughout the U.S. Maria Feng, civil & environmental engineering professor at the University of California, Irvine, is leading a team with two companies that specialize in making repair materials and applying them to city infrastructure. The robot would save time and cost of digging and fixing, and it will have easy access to places in the cities where digging is impossible or difficult. The repair robot would be inserted inside the pipe of the water system where it will travel until it finds a break or weak point and apply a patch of tough reinforcement material and repair the damage. Obstacles the project may face are determining an accurate way for the robot to identify the flaws inside the pipes, as well as finding a way for the robot to apply the reinforcement material. To tackle one of the obstacles, the team is integrating an advanced sensor system into the robot that can measure contact pressure against the sides of the pipe which will activate the repair process if it’s needed. The team leader Feng, explains that if the project succeeds then a commercialized robotic system could save the U.S. economy about $245 billion and give the U.S. a lead in the world market for water infrastructure technology.

3. In-Pipe Running Robot and Method of Running the Robot
An in-pipe running robot [14] includes a vehicle body movable inside piping along a piping axis, and a pair of running devices disposed in front and rear positions of the vehicle body. The robot is an in-pipe running robot used in various operations inside pipes such as inspection of interior conditions or repairing of inner walls of pipes. The wall repairing process occurs by adhering the running devices (robots) to walls, through a magnetic field formed between the robot’s pair of wheels and the surface of the wall. Devices used in data communication between the in-pipe running robot and the system disposed outside the piping includes a reel mounted on an upper rear position to hold a predetermined amount of information being transmitting through fiber optical cables. The robot runs straight along the piping axis to arrive at an intended location quickly or to inspect piping bottoms successively which are the most susceptible parts of the piping. The robot is required to run circumferentially in the piping to inspect or repair the joint as necessary where the piping includes a welded joint formed circumferentially.

4. Autonomous Mobile Robot in Pipe for Piping Operations
The paper [15] discusses an autonomous mobile robot that can move in vertical and horizontal pipes as well as elbow joints with a 90° angle. The robot has a rotating vision sensor and an operating arm in front of the robot body to execute piping operations such as inspection of pipe surface, welding of the pipes and more. The robot is built by several units with four wheels
connected by universal joints joining each other. The robot is controlled by a microcomputer chip and a host personal computer. Each unit has four wheels and they come in contact with the inner surface of the pipe. The wheels have a mechanism to be movable in a radial direction, and the wheels press against the inner surface of the pipe by springs. The rotation of the wheels is controlled by controlling the DC motors using the PWM control method and the rotational speed of the motors is monitored by rotary encoders. LEDs around the CCD camera are used for lighting the path of the robot. When the robot moves in a pipe, a CCD camera and a laser pointer are used to observe and detect an elbow joint and a T-joint in order to confirm the pass. If the robot detects a joint, the driving mode of the robot changes from straight mode to corner mode. The robot can observe and inspect the inner surface of the pipe and can also detect welding lines and track the tip of the operating arm along the welding line.

5. Internal Pipe Inspection Robot
The paper [16] describes a robot that inspects gas pipes underground internally and climbs over sharp obstacles like sleeve and dresser joints using dual magnetic wheels. The robot uses fiber optic communications to eliminate the difficulty of using cables for power and communications. A vision system of the robot makes it able to clearly view and inspect the welded section underneath the robot while gazing ahead for navigation.

2.7 Comparison Between The Similar Product and Our Project:
After Going through each similar project and product and analyzing the features and techniques in each one, the following conclusions were found. The “Robotic System to Locate Hazardous Chemical Leaks” only detects leakages without repairing it. As for the “Robots to help repair aging water pipes”, the robot places a patch that might not be the same size of the hole or it doesn’t cover the entire cracked area. Also, “In-Pipe Running Robot and Method of Running the Robot” has the issue of the magnetic field that’s created, and the robot not working because of the material of the pipe, as well as it not being able to reach all leakage areas such as the one passing by a T-junction curve. As for the projects “Autonomous Mobile Robot in Pipe for Piping Operations” and “Internal Pipe Inspection Robot”, the welding operation would be dangerous and risky and the heat might damage the pipe, or the welding may be executed in a way that may not repair the pipe. On the other hand, the Robot we created would repair the leakage and the swinging operation of the nozzle would cover the entire crack. It would also reach any leakage inside the pipe network and would not create any heat inside the pipe when spraying the sealant and repairing the leakage.
3 Designs and Analysis:

3.1 Design Requirement
To perform an auto-repairing operation, a robot’s design should meet the following requirements:

1. Fit the area inside the PVC’s pipes (4-inch diameter)
2. Can carry the repairing kit.
3. Be able to apply it in the detected area.

3.2 Required Components and Tools
To create the robot that handles the mentioned features, numerous components are needed such as:

- Sealant material: to adjust the leakage
- Servo: to depress the nozzle in the can allowing the pressurized sealant to flow out.
- Gear: to transfer power from the gear motor to the turret.
- Geared motor: To turn the turret.
- Battery: to run the servos and gear motor

The table below (table 1) shows the selection for each required component and its specification.

<table>
<thead>
<tr>
<th>Name of the Component</th>
<th>Selection</th>
<th>Specification</th>
</tr>
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</table>
| Sealant Martial [17]  | Permatex 82099 Spray Sealant                  | • Durable rubber barrier stops leaks in minutes  
• Targets leaks in hoses, oil pans, differentials, transmission pans, plastic, PVC, and metal pipes  
• Seals hard-to-reach leaks without the need for disassembling or removing parts  
• Resists common shop fluids |
| Servo [18]            | Hitec 32225S HS-225MG Mighty Mini Servo        | • Size in Inches: 1.27 x 0.66 x 1.22, Size in Millimeters: 32.26 x 16.76 x 31.00, Weight ounces: 1.10, Weight grams: 27.94  
• Torque oz./in. (4.8V/6.0V): 54 / 67, Torque kg./cm. (4.8V/6.0V): 3.9 / 4.8 |
| Spur Gear [19]        | G-made 81415 32 Pitch 3mm Hardened Steel Pinion Gear 15T | • Dimensions: 4 x 3 x 1 inches |
| Geared Motor [20]     | Amico 300RPM 12V 0.6A High Torque Mini Electric DC Geared Motor | • Gearbox Size: 16 x 13mm/0.63" x 0.51" (D*H); Overall Size: 16 x 53mm/0.63" x 2.1" (D*H), Diameter: 3mm/0.118" |
3.3 Custom Manufactured Parts:
The following parts were designed in-lab and manufactured using a Stratasys Fortus 250mc 3D printer.

- Turret: to rotate the nozzle and hold the servo

![Figure 1 Turret](image1)

![Figure 2 turret with the servo](image2)
• Clamping rings: to hold the spray can, to hold the gear motor, also wheeled for mobility

![Figure 3 Clamping Rings](image3.png)  ![Figure 4 Wheel](image4.png)

Figure 3 Clamping Rings  Figure 4 Wheel

![Figure 5 Clamping Rings with the Wheels](image5.png)

Figure 5 Clamping Rings with the Wheels

• Top and bottom struts: to hold the clamping rings together

![Figure 6 Top Strut](image6.png)

Figure 6 Top Strut
3.4 Design Alternatives
The design of the robot is fixable, so there are several design alternatives. One alternative is to use a different type of sealant material, like Rescue 911® Instant Leak Sealer [22], which can repair a small leakage hole within 3 minutes. A more develop version of the project may include a cover on the nozzle stick to isolate the leak from the fluid. The repairing process also can be controlled by an expert from the system interface that is integrated with the robot.
4 Implementation

4.1 Project Diagrams

- The following models (figure 9, 10, 11, and 12) were created using SolidWorks 2012. These models show integration with the spray can, electronics, and pipe.
4.2 Project Images:

- The following figures (figure 13, 14, and 15) are the real design of the robot that was manufactured using a Stratasys Fortus 250mc 3D printer.

Figure 13

Figure 14

Figure 15
4.3 Control Interface:

- The following figure (figure 16) is the interface that controlled the robot and was created under lab view:

![Control Interface Image](image-url)

Figure 16 Control Interface
5 Evaluations:
After manually testing the two repairing sealants for a small hole in a PVC pipe, the results are shown in figure 17 for Permatex 82099 Spray Sealant (7 min to cure) and figure 18 for Rescue 911® Instant Leak Sealer:

Figure 17 Permatex 82099 Result (7 min to cure)

Figure 18 Rescue 911 Result (5 min to cure)
Other manual tests were done for the two repairing sealants for a big hole in a PVC pipe, the result shown in the figure 19 for Permatex 82099 Spray Sealant and figure 20 for the Rescue 911® Instant Leak Sealer result:

Although Rescue 911 sealant take less time than Permatex 82009 sealant to cure, Permatex 82009 can repair the leak from small and big holes in pipes and the Rescue 911 sealant can repair only a small hole. Also, the required time to cure for both depends on the thickness of the sealant layer, i.e. thicker layer needs more time to cure for both sealants.
6 Conclusion
Nowadays, many tools and equipment are available for professionals to combine and use them in offering services. In this project, some of these tools and equipment are combined and used to create a robot that can repair leakages in the pipe network. By having such a robot that can handle the leakage situation, people would save time, money, effort, and avoid being at risk while repairing leakages in pipes. The first version of the robot proved to be successful in repairing leakages from inside the pipe itself. Also, as noticed in the first draft version of the robot it shows that it can be developed and enhanced to become more intelligent and be able to repair any leak inside the pipe network. The swinging nozzle feature makes it possible to cover the entire area of the leak. Moreover, the robot has an advanced mobility feature where it can move in any type of pipe network and also the robot itself can be improved to be smaller in size to tackle small pipe diameters. Finally, with technology improvements and developments, the robot’s repairing operation will be advanced and will be completely decentralized, independent, and automated without the need of the human interference.
Acknowledgement
The author wishes to thank the supervisor Prof. Kamal Youcef-Toumi on his support and valuable advises throughout the entire research period. Furthermore, I would also like to thank the team for their kindness and helpfulness in the mechatronics laboratory, Dimitrios Chatzigeorgiou, You Wu, and Frederick Moore. I took effort in my research in the mechatronics laboratory; however, it wouldn’t have been executed without them all. Last but not least, I would like to thank Dr. Murad Abu-Khalaf from the Kuwait-MIT Center for Natural Resources and the Environment for his assistance and guidance for this research.
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doi: 10.1109/ROBOT.1995.525390

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