AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #36027

SEWAGE PIPELINE INSPECTION TOOL & ROBOT

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SEWAGE PIPELINE INSPECTION TOOL & ROBOT

Abstract

Pipelines are essential infrastructure for water supplies, oil/gas transportation, and sewage transportation. Of these, sewers are often affected by their operation environments where untreated human and industrial waste causes degradation and corrosion resulting in the leakage of toxic effluents into the environment. A complicated pipe network significantly increases the difficulty of inspection.

The conventional pipe inspection methods are vision, ultrasonic, laser, and x-ray. Under these cases, novel inspection methods were proposed such as using the electromagnetic field and microwave. These methods can operate in more complex pipe environments and provide more accurate results. Despite the fact that these state-of-the-art methods of inspection are efficient and accurate, the mainstream method is visual inspection using color cameras. Inspecting a storm drain often requires visual inspections, but in some cases, challenges arise for untrained personnel to perform the inspection. This becomes problematic when an inspection needs to be performed regularly, otherwise, the rate of debris buildup can lead to greater issues down the line.

In this research, a self-propelled robotic device was proposed that utilizes both conventional and novel instruments for in-pipe inspection to increase the amount of retrieved data that extends beyond visual scans to allow a more thorough evaluation in determining the health of an aqueduct. In this paper, modular sensor system was presented. The modular sensor system has the ability to integrate the necessary sensors for novel inspection methods and the potential to upgrade in the future.

I. Introduction

Inspecting pipelines is a necessary process to ensure the smooth operation of the facilities of debris and waste management. The pipeline must be inspected regularly, and the quality of the inspection must undergo thorough procedures. Minimal data that is useful would be extracted from the process, otherwise.

The inspection process poses a danger for people due to the contents of the pipeline that is being inspected and often include decomposing material that releases harmful gasses and causes bacterial growth. An additional problem that arises is the depth at which the pipeline can be observed. The standard sewer pipeline can range from 40 to 80 feet in length between joints. There are existing products that can route a camera up to these lengths; however, the solutions are costly and can benefit from a reduction in price.

Pipelines are some of the most important pieces of an urban area's water supply, oil/gas transportation, and sewer transportation [1]. Within these categories of pipelines, sewer pipes are one of the easiest pipelines that could be affected by their operation environments, untreated human and industrial waste, causing defects and corrosion. This results in the leakage of toxic effluents polluting the environment [2]. The conventional pipe inspection methods are vision, ultrasonic, laser, and x-ray [3] - [5].

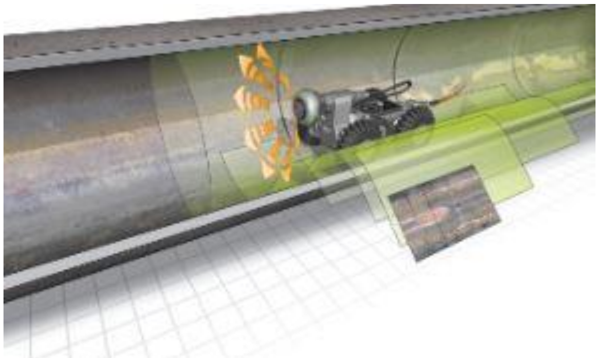

Fig. 1: Visual scan of pipe internal by a wheeled-robot [6]

In terms of in-pipe inspections, the methods were limited to vision, laser, and ultrasonic inspection as shown in Fig. 1. These three methods have their limitations as the following [7]: Vision inspections are facing the difficulty of inspecting defects and corrosion the small dimensions; laser inspection has the difficulty of its navigation in inflow environments [7]; lastly, ultrasonic systems have constraints of operating properly in the condition of the pipe is both dry and flooded [7]. Under these cases, novel inspection methods were proposed, such as using the electromagnetic field and microwave [8] - [10]. These methods can be operated in more complex pipe environments and have more accurate results. More sophisticated devices such as the Aries Industries shown in Fig. 2 include a locating beacon in addition to its CCTV camera but not much more. In this project, the process of designing an inspection system that utilizes both conventional and novel inspection methods for in-pipe inspection is researched.

Fig. 2: Aries Industries Pathfinder TR3320 robot with infinite rotation camera [11]

II. System function requirement

For such a robotic system, we can divide the systematic need for it to function. In this project, the team developed a remote-controlled robotic system, with the following objectives:

- Sensors

The goal of this project is to inspect sewage pipelines; sensors are necessary to perform the task of inspections. This includes modules such as cameras and independent sensors such as IMU, Pressure sensors, chemical sensors, etc. These sensors will give the operator detailed information about the pipeline.

- Communication

Communication of the robot can be broken up into two parts: internal communication which the controller connects to peripheral sensors, actuators, and motors; and external communication to let the operator control the robot remotely.

Internal communication was implemented by using digital communication protocols such as UART, SPI, or I2C. These are communication methods that are commonly used in embedded systems. Many of the microcontrollers (MCU) and embedded platforms have integrated libraries to utilize these communication methods. Each of these communication protocols has its own advantages and disadvantages. For example, UART has the benefit of easy debugging using a digital analyzer but lacks the capability of one-to-many bus communication, thus the number of communications are constrained by the availability of MCU, or device provided.

External communication, on the other hand, has a wider range of selection. It can be implemented using any type of wired and wireless communication. One of the big differences between external and internal communication is that internal communication is usually simplex or one-way communication; external communication is always duplex communication in order to both monitor the robot and controls it at the same time. Overall, external communication can be categorized into wired and wireless. The selection of methods was dependent on the cost, reliability, and bandwidth.

- Maneuvering

In order to move inside the pipe, the robot is required to have a maneuvering mechanism such as a set of motor drive wheels. But the maneuvering mechanism does not limit to wheels, it can be anything that lets the robot move as the operator desires. The selection of the motor for the design varies on the target accuracy of control. A brushed DC motor is the simplest in terms of development, on the other hand, stepper motors with encoders offer greater accuracy. There are various options in between such as brushless DC motors with encoders or AC induction motors. Having the encoder integrated into the maneuvering module is able to develop the control logic of a feedback system, which is more accurate than a feedforward system without any sensors.

- Power

A necessity to make each and every part of the robot work is power. In this case, electricity is required for modules such as controllers, sensors, motors, and communications. There are different ways to provide power to the robot but it can also be categorized into external power and internal power. The external power supply can be powered over wires to the robot. Another option is to combine power delivery with communication to the robot such as USB Power Delivery or Power Over Ethernet (PoE). The internal power supply method can integrate batteries inside the robot.

III. System Design

In our design of the robotic system, we split the overall system into many independent and interconnected subsystems.

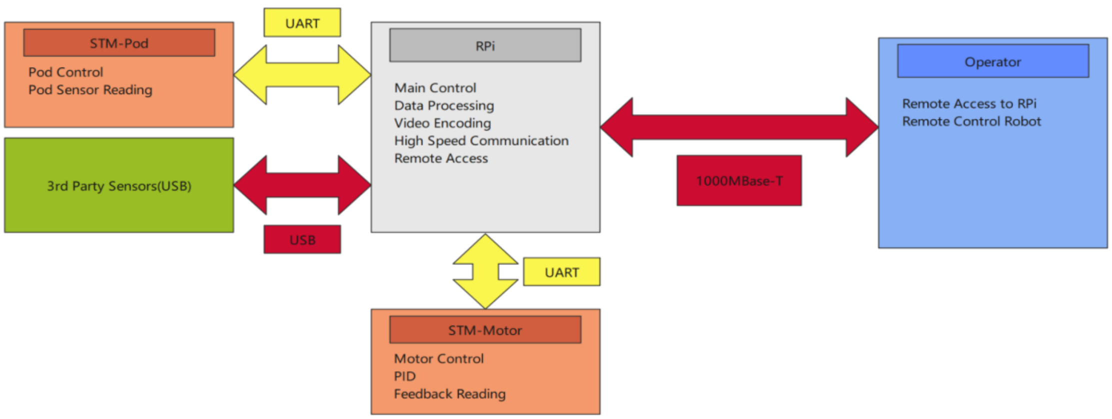

Fig. 3: Systematic diagram

The robotic system includes the main control section which we use a Raspberry Pi as the central control computer in the robot. The external sensor was planned to integrate into a pod, which contains a microcontroller for receiving sensor data and sending the data packets to the Raspberry Pi. This allows the design to have the ability to integrate multiple sensors into the sensor pod. There is an additional sub-control system in the robot which is used for the purpose of motor control, this simplified the development of integrating features such as PID control for the maneuvering mechanism of motors.

In the design of the project, Power-Over-Ethernet was used. Since PoE combines communication and power delivery into a single twisted CAT8 cable, the design of the communication section and powering section can be more compact in the robot. There are PoE receive splitter modules available on the market which decrease the cost of development. These modules have the functionality of splitting PoE to standard ethernet and independent 12V power.

Logic supply to power the microcontroller and microcomputer, both 3.3V and 5V were needed and was done using a Low-dropout regulator (LDO) and DC-to-DC converter (DC-DC). Each of these has its own advantages and disadvantages. The setup of LDO is very simple and has low output noise, but the issue with LDO is that the efficiency of the device is highly dependent on the ratio of input-output voltage, in the case of 12V in, 3.3V out, the theoretical efficiency is less than 30%. On the other hand, DC-DC has the advantage of being highly efficient and can handle large currents. The drawback of DC-DC comes down to the possibility of noise, the complexity of the setup converter, and cost.

Considering the advantages and disadvantages of LDO and DC-DC, DC-DC was the chosen method with some additional techniques to avoid the potential drawbacks.

In the design of the DC-DC, compared to the buck DC-DC setup, the push-pull configuration has slightly higher efficiency and much lower output noise. Comparing a push-pull setup to a full bridge setup, the cost is significantly lower.

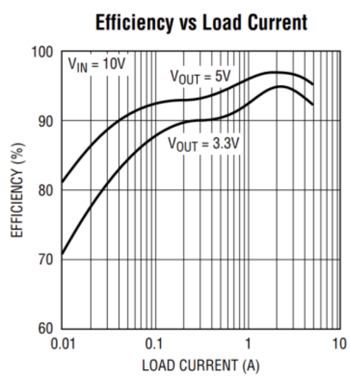

Fig. 4: LTC1625 Efficiency vs Load [12]

In the component selection, a high-efficiency DC-DC control IC was selected based on the intended output voltage and output current.

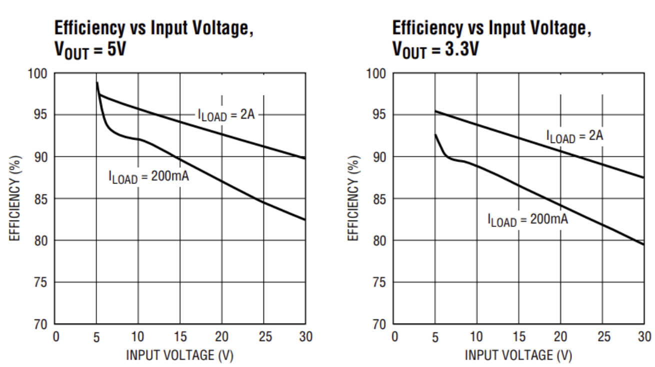

Fig. 5: DC-DC Efficiency curve[12]

LTC1625 is a DC-DC control IC designed for low-power DC conversion. The voltage conversion efficiency is between 92% to 95% for 12V to 5V conversion, and 88% to 93% for 12V to 3.3V conversion.

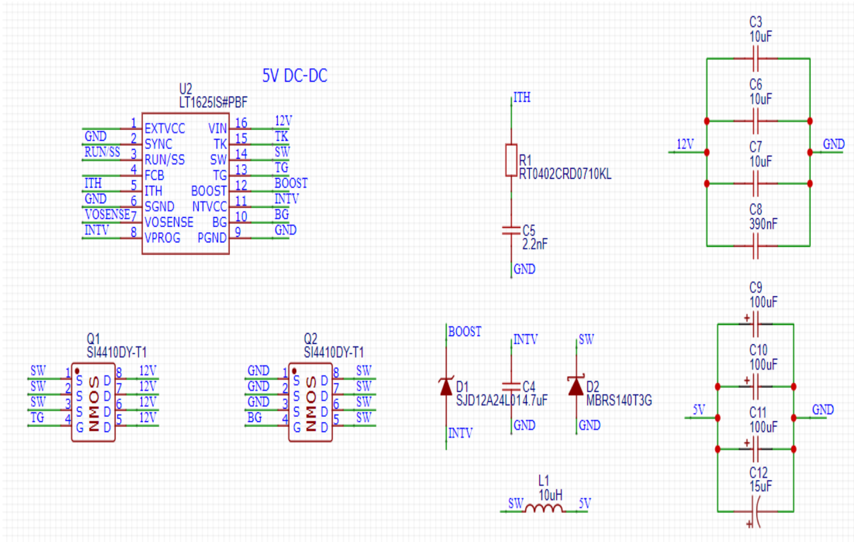

Fig. 6: DC-DC Schematic (12-5)

To further decrease the effect of noise and the possible cause of noise to the 12V supply rail, additional decoupling, and bypass capacitors were added to the design. A combination of large and small capacitors can efficiently filter out the high-frequency noise in the circuit (Fig.6).

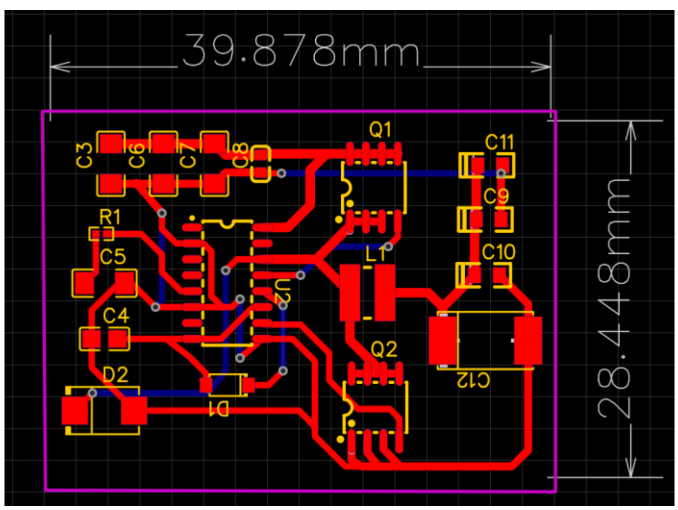

Fig. 7: DC-DC layout

After the layout of the converter, the size of a DC-DC module should take no more than the size of 3cm x 4cm. With the capability of supplying 5V @ 2A or 3.3V @ 4.5A, the module is capable of serving the intended purpose and the cost of each module is about $12.

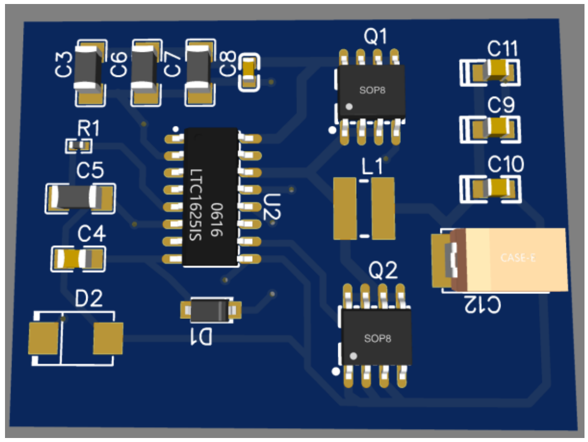

Fig. 8: PCB render

For the microcomputer (MPU) of the robot, we were using a standard Raspberry Pi 4B. The reason this model was selected as the MPU for the robot is due to its simplicity of debugging and the plethora of resources available for its development. The computing task of this MPU is to receive data collected from the sensor pod, and the video feed from the navigation camera. It also drives the motor's MCU for the maneuvering of the robot.

For controlling the robot, the approach in this design was using Virtual Network Computing (VNC), which provided remote access to a computer within the same network. Since the design used PoE as the power source, it did not require additional hardware to provide the feature of accessing the MPU with ethernet. Since the Raspberry Pi 4B has an ethernet port included the way to set up the access was to connect the ethernet to the operator's computer. Thus, the operator can directly be doing remote access to the MPU inside the robot.

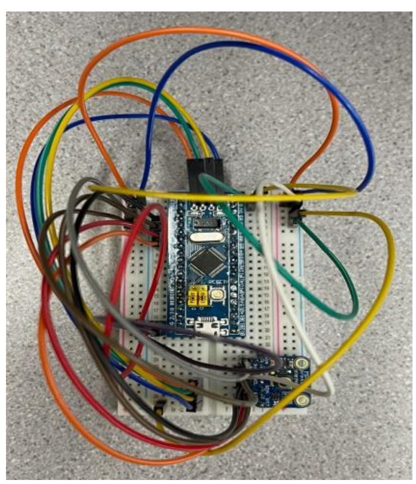

Fig. 9: Early Prototype of the Pod with Pressure Sensor

One of the key features was the interchangeable sensor modules integrated into a sensor pod. The sensor pod is interchangeable depending on different operating environments. The pod will include an MCU with different sensors, and the power will be supplied from the main robot.

IV. Testing Results

The systems working in parallel have been demonstrated in an initial state. Further testing and optimization must be done after this initial process. Fig. 10 shows the working camera module paired with the visual display of the microcomputer over the network. This have the advantage of lowering the requirements of hardware in the operator's side since the computer works as a terminal and all the load of computing is on the robots.

Fig. 10: Demonstration of functioning camera over the tether cable

Fig. 11: Completed data & power configuration for single-cable operation of the microcomputer

The setup shown in Fig.11 demonstrates the network connection present for the robotic system. The system will have the single tether shown with the PoE (Power over Ethernet) supply to connect on the network side of the control system. The demonstration of this is shown in Fig. 10 where the connection established was present over the single cable of the network.

V. Conclusion

Inspecting pipelines is a necessary process to ensure the smooth operation of the facilities of debris and waste management. However, the inspection process poses a danger for the inspection personnel. The objective of the project was to design a pipeline inspection tool to reduce the risk exposure of inspection personnel to toxic gasses. A prototype of the sewage inspection tool and robot was designed. The design required considerations of the inner diameter of the pipe, potential obstacles, and sensing. The system required a minimum of visual inspection processes to proceed. The sensing system was integrated to be interchanged as needed. The systems that controlled the visual inspection, motor control, and sensing monitoring were constructed for the prototype model. Initial testing showed VNC is a reliable method of remotely controlling the robot, in addition, the accessibility of the robot's system instead of only having the camera view gives more control over the system. Thorough testing, alternative methods were discovered that could potentially improve the system, such as using fisheye camera with calibration instead of regular camera would give a wider range of view. The further inspection should be completed in the near future.

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