# A Novel Tracing and Localization Inspector Robot Based on Pipelines Flexibility

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**Abstract:** This paper combines two different robotic modules to form an integrated module for inspection of underground oil pipelines. It also discusses the tracing and localization technology of wireless robots inside pipelines. The main concern of this technique is to establish a reliable communication between inside and outside of metal pipelines. Based on the satellite multiple measuring module principle, the main purpose of pipeline positioning module (GPS) is to trace long distances and localize defects around desired location. This study seeks a method of low-power-consuming communication module design as well as a communication protocol. Field tests approved the efficiency of tracing and localization module so that it can be used by various types of pipeline-inspecting robots to provide automatic movement.
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## 1. Introduction

Pipeline is an important equipment to transfer oil products, water and gas. The daily-growing use of pipelines makes their maintenance, defect revelation, and design methods quite indispensable. Such requirements have led to the development of pipeline robotic modules along with some advanced inspection techniques such as optical inspection, magnetic inspection, eddy current, ultrasonic inspection, acoustic method and so on. These methods are quite useful for revelation of corrosion, leakage, and welding defects. The complexity and variety of pipelines in industrial environments accelerates the invention of new robotic modules. Among them are wireless automatic movement, reliable communication between inside and outside of pipelines, long term operation, and accurate tracing and localization. As was in the past [1, 4], some challenging and problematic operations of pipeline engineering such as leakage control, pipe wall repair, sediment cleaning, and replacement of old pipes usually required exhausting and costly digging operations around pipeline. This method is highly expensive and may harm pipe wall itself. Thus it is necessary to develop some cheaper and safer test methods [2]. For robots navigating within pipes, tracing and localization technology is of vital importance. Here, we have studied the development of some robots for inspection inside pipelines and also have developed their inspection techniques [6]. Nowadays, localization techniques such as speedometer wheel, control cable, rays (X-ray and Cobalt 60 Isotope radiation, etc.), static magnetic sensors, and acoustic method are globally studied and widely used in spite of their deficiencies for the application in pipeline engineering. Speedometer wheel technique is an inside-pipeline method and is only able to gather information from an out-line location. Control cables limit the independent movement of inspector robot and decrease its operation range [11]. Although ray is biologically harmful for environment, it is able to penetrate metal pipes and inspect their defects. Its penetration time is so short that localization operations can be carried out through a limited region. Magnetic method is applicable to many regions through robotic localization [15]. Hall sensors are placed on pipeline at similar distances from each other and a permanent magnet is planted on a robot. A signal is given out to inform operators when robot passes each sensor. The localization accuracy of this method is low because sensors are distant from each other. Acoustic method is easily disrupted by mechanical vibrations and environmental acoustic sources [16]. In addition, other localization methods such as ultrasonic, radio frequency and radar usually require high frequencies which are totally absorbed by metal pipes. Tracing and localization by robotic modules relies on the establishment of a reliable connection between inside and outside of metal pipeline. The robotic module, presented in this paper, has a structure of joints which gives it a snake-like shape. These modules can be divided into two groups: active and inactive driving force modules [9]. Inactive movement of robotic module is achieved by internal pressure of pipeline, while active robotic module has a set of electrical motors to automatically push it forward inside pipeline. This paper mainly studies the tracing and localization by robotic module inside pipelines using the electromagnetic pulse of very low frequency (ELF-Electrical Pulse) which is highly penetrative into metal, water and/or dust [13]. Based on multiple satellite measuring principle, this module is supposed to consist of an ELF-Electrical Pulse transmitter, three rows of sensors and an information processing module. The law of ELF-Electrical Pulse transmission and distribution within pipelines is also analyzed in this study [10].

## 2. Structure of the Robot Modules

This section describes the robotic module design and its importance.

2-1 module with inactive driving force

This module, shown in figure (1), is also called Pig. The proposed robot has a structure of joints which consists of rubber disks, power supply, power controller, tracking and localization unit (TLU) and ultrasonic inspection part. Rubber disks hold the capsules at the center of pipeline and causes pig to move inside pipeline by blocking fluid path. Power supply generates a 24V direct current, allowing it to continuously operate with its full capacity. Power controller regulates the power supply current. Controller is located inside the capsule of an industrial computer (PC-104). A speedometer wheel is planted on capsule to measure the distance passed by pig inside the pipeline. It continuously keeps in contact with interior side of pipe wall and generates an electric pulse per circle. TLU is necessary for robot inspection, for instance, robot may block pipeline when there are obstacles inside it or any distortion on its wall [2]. Details will be discussed in following sections. Ultrasonic inspection uses 64 ultrasonic transformers planted on a mechanical support in capsule plug. Transformer is used through pulse-echo method to measure echo duration along pipeline while inspecting pipe wall thickness. Quality of pipe wall is analyzed and its situation is determined according to the distances reported by speedometer wheel and data obtained from ultrasonic inspection. While inspecting pipelines, pig neither affects nor poses any obstacle to the products inside the pipeline. Pig movement is only related to pressure of the fluid passing through the pipeline. In addition, pig is a very suitable pipe cleaner since it capable of removing the sediments lying on interior side of pipes.

2-2 module with active driving force

As shown in figure 2, robotic module with active driving force (also called creeper) also has a structure of joints which consists of driving part, driving controller, power supply, power controller, robotic central controller, TLU and ultrasonic inspection. Driver is the first difference between pig and creeper. The driver unit pushes creeper forward which consists of 6 active wheels. There is a DC motor inside each mobile arm. A DC motor is used to move robot inside pipelines with diameters varying within a wide range. This mobile arm can be regulated in radius direction so that mobile wheels will continuously be in contact with pipe wall. All motor drivers and movement control circuits are located within movement controller capsule, to provide sufficient elasticity. Controller Area Network (CAN) is also established in this module. Driver controller, power controller, TLU and ultrasonic inspection are all the end devices which are able to communicate with central controller directly. Communication protocol consists of instructions such as automatic checking, velocity control and motor movement direction, diagnosis and alarming. Each part of robotic module is independent of other parts so it can simply be connected and disconnected without affecting the normal operation. Creeper can be used for oil, gas and water pipelines. Are capsules test under 2.5 MPa fluid pressures, without considering leakage. Furthermore, the floating power of pipeline can reduce load of locomotive objects.

2-3 GPS Operation

GPS offers two possibilities: robotic tracing of long distance and localization of pipeline cracks throughout a certain location. The tracing methods for both robotic modules are the same. When robot moves inside a pipe, TLU sends an electromagnetic pulse signal of very low frequency. Operators can detect it by receiving signals through the sensors. Although there are differences in localization process of pig module, speedometer wheel produces pulses during movement alternatively. Production of no pulse for a duration of 5 seconds means that pig has jammed inside the pipe. Then central controller sends an alarm to TLU. Based on localization algorithm, sensors are able to reveal pig`s location inside the pipe. Whenever creeper faces such critical situations inside pipelines, the same calculations are made to solve the problems. In another situation, the ultrasonic inspection immediately gives the central controller and moving parts a sudden order to stop moving while finding a crack on pipe wall. To avoid inspection errors, mobile parts are adjusted for three times by moving forward and backward slowly. 64 ultrasonic transformers inspect the whole pipe wall and find the exact location of cracks. Then, localization process continues similar to the process in the case of blocking.

## 2-4 Requirements for TLU Module Design

Industrial pipelines are mainly located underground or in sea bed. Thus, high-power electromagnetic signals are required to be capable of transmitting through oil, metal, sea water, and dust. Essentially, transmission distance in vertical and horizontal directions should be more than 5m and 20m respectively. As mentioned above, when there is a mistake in robotic module or a crack on pipe wall is found, creeper should stop moving and TLU start sending alarm signals. In addition, signal frequency and power control of an intelligent controller are necessary for TLU to provide communication services. Signals power significantly declines during transmission. Receiver sensors should be sensitive enough to transform magnetic signal to electrical signal. These sensors may be affected by other environmental sources of frequencies since they have wide band. The design of pipeline defines total size of the robot. Considering the common trend in use of multipurpose micro modules, the present technology is differentiated from others because its possibilities including operator, driver, electronic power supply, sensor and communication appliances are all located in a very small space.

## 2-5 TLU module

TLU module is a combination of TLU (inside pipeline), sensors and signal processing circuits (outside pipe). TLU consists of a capsule, two caps, a transmitter, embedded controller and battery. The equipment inside the capsule is fixed with two rubber disks to prevent vibration. The low-frequency electrical pulse transmitter consists of pulse generator, amplifier and coil which are embedded in a sealed capsule. Pulse generator controls frequency and amplitude of electromagnetic signals (Electrical Pulse). Pulse generator alters electrical pulse signal with amplitude oscillations in order to improve instant transmission power, considering the limited capacity of battery [22]. Two things should be assured of TLU: working normally and alarming the localized defect. Power amplifier is designed as an external tubular transformer which operates using power supply. Coil is an inductive load that prevents current from sudden changes. Soft switch technique is used to reduce primary power consumption. There is a powerful capacitor inside the coil. It is better to wind the coil so that its two narrow parts keep connected in parallel at the same distances. This method reduces resistant load, while the capacitor is used to enhance transmitter power and reduce power consumption.

## 2-6 Transmitter controllers

As shown in figures 1 and 2, two cables are connected to each capsule. One is power cable (24V direct current) and the other is communication cable (CAN). Transmitter power amplifier, which works with 14-15V current, needs a leveler transformer. Developed microcontrollers (ARM) are used to establish a connection between input and output components and CAN. The Controller consists of voltage identification circuit, power switch circuit, charge circuit and ARM embedded controller [25]. A battery within TLU acts as the emergency power. When power supply module stops working, controller can continue operating with this battery along with transmitting an alarm to central controller through CAN. Communication protocol between inside and outside of pipeline is established by the help of embedded controller and pulse generator. Transmitter`s Electrical pulse signal is regulated by pulse generator and is determined by embedded controller based on automatic diagnosis and CAN communication with other parts of the robot.

## 2-7 Signal receiving module

Electrical pulse signal of very low frequency is magnetized through inductive sensor. The sensor consists of a coil and a magnetic core. According to the Faraday electromagnetic induction law, when magnetic flow passes through a charged closed coil, a driving force is produced in coil by the inducted electrical current. The sensor is located in a time-varying magnetic field, and Electrical pulse signal amplitude is transformed to an electrical current of -5 to +5V. This phenomenon is mathematically expressed as follows [20]:

N= number of coil rings,
S= equivalent level,
μ= magnetic permeance
and ------ time-varying magnetic field.

The electrical driver force amplitude $\varepsilon_0$ is also expressed by:
Where ----------- is sensor constant.

The receiver module of electrical pulse signal consists of sensor, filter, information acquisition device and computer. Signals are sent from Sensor`s output to filter and amplifier in order to distinguish useful signals, then signal samples are transferred to computer. 5 active filters are designed to achieve higher quality. Filters consists of 5 parts including amplifier I (high quality passing filter), band I passing filter, amplifier II (band I passing filter), band II passing filter, and amplifier III (high quality passing filter).

2-8 pig in pipeline

Pipeline pig is usually used to remove sediments from oil pipelines. This process is highly required prior to creeper entrance into the pipeline considering creeper’s limited ability to remove obstacle. Firstly, pig moves through pipeline for about 20m, riding on the high pressure gas produced by air compressor. Localization technique is used to control ventilation time in this process. A rope is fastened to end of the pig to compare the result of localization technique with the distance traveled by pig. Rubber disks’ diameters are 1.2 times of pipeline’s internal diameter. Hence, they must overcome the attrition inside the pipeline. At second stage, compressor faucet is closed and output faucet is opened in order to reduce the internal pressure of pipeline to the level of atmosphere pressure. The operator may be under threats for 20 minutes. At third stage the pipeline is filled with water and the rope fastened to pig is shaken to send air bubbles out to prevent the errors caused by these bubbles during ultrasonic inspection. At forth stage, another rubber ball enters the pipeline and is pushed forward using high pressure gas. The Water column between two rubber ball acts as an insulator between ultrasonic probes and internal wall. Using sensors, filters, amplifiers and software, the progress distance of low-frequency electric pulse signal can be measured in both horizontal and vertical directions, subsequently. Progress distance is defined as a range of inductive signal amplitudes bigger than 0.1V. This test is replicated for three successive times. Pig movement velocity is adjusted by changing input pressure. Localization errors are usually less than 0.45m, that is, error velocity is less than 5% and it is concluded that error can be reduced by decreasing input pressure.

## 3. Test and Result

Creeper, by the help of its driving force, can move inside pipe even with low velocity. Thus, in this case there will be enough time for inspecting welding of any type. Welding circle can simultaneously be inspected in axial and tangent directions by alternate distribution of ultrasonic transmitter. When ultrasonic inspection finds a defect, creeper stops and moves three times in that range to identify the exact location of the defect. Then, TLU starts working and identifies the location of creeper accurately. The marking rope, connected to the robot to measure its distance, is also used to draw it out in the case of incidents. The robot stops where the defect exists for 10 minutes and then, starts moving. Three rows of sensors with a distance of 1.5m from each other are embedded to accurately identify the robot location. Figures 6 show communication protocols inside and outside the pipeline. Normal state shows there is no defect. Defect alarm warns operator about a problem in robot or pipeline. Test results show that ELF-electrical pulse signal can penetrate into metal pipe wall and oil layers. Logical and trustworthy relation between inside and outside the pipeline has been shown. TLU technique meets industrial requirements and its efficiency is approved by experimental applications.

## 4. Results

Two robotic modules with two different types of driving forces for ultrasonic inspecting of underground oil pipelines were studied in this paper. Robot, in this method, was used for inspection as a mobile and a localized equipment. The paper mainly investigated the use of TLU technique in pipeline robots. The problem of electromagnetic signals overlap inside metal pipelines was also solved by embedding ELF-electrical pulse to transmit messages. Thus a reliable communication was established between inside and outside the pipeline and communication protocol was found to be quite effective. It is concluded that TLU is able to operate as an independent module so that it will be applicable in robotic modules for various types of pipelines. More field tests can be done using this method. On the other hand, it is foreseen to equip it with a GPS to monitor pipeline through far distances.

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