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Drive Control System for Pipeline Crawl Robot Based on CAN Bus

H J Chen¹, B T Gao¹, X H Zhang¹ and Z Q Deng²

¹ Department of Electrical Engineering, Harbin Institute of Technology Harbin, Heilongjiang, 150001, China
² School of Mechanical Engineering, Harbin Institute of Technology Harbin, Heilongjiang, 150001, China

E-mail: hongjun@hit.edu.cn

Abstract. Drive control system plays important roles in pipeline robot. In order to inspect the flaw and corrosion of seabed crude oil pipeline, an original mobile pipeline robot with crawler drive unit, power and monitor unit, central control unit, and ultrasonic wave inspection device is developed. The CAN bus connects these different function units and presents a reliable information channel. Considering the limited space, a compact hardware system is designed based on an ARM processor with two CAN controllers. With made-to-order CAN protocol for the crawl robot, an intelligent drive control system is developed. The implementation of the crawl robot demonstrates that the presented drive control scheme can meet the motion control requirements of the underwater pipeline crawl robot.

1. Introduction

Industrial ductwork has been wildly used in metallurgy, petroleum, chemical engineering, water supply and other special professions. The formidable work environment makes pipeline easy to be eroded or fatigued which can lead to leaking accident, so the periodic maintenance and overhaul are necessary for industrial pipelines. Currently, in-pipe robot with tether, which enables the robot to have the enough energy supplies and promptly make up the power loss, still has important application value owing to avoid carrying a heavier energy devices, but the noticeable friction forces of tether restrict the traction force of robot, locomotion distance away from entrance, and the steering inside pipelines with elbows. Therefore, the development of autonomous in-pipe locomotion robot without tether becomes urgent, such that the robot can be adaptive to the work of long and complicate pipeline [1, 2].

One of the key techniques to develop in-pipeline locomotion robot is electrical drive. More driving spots, more flexible action, lower power consumption and other special requirements are making the motor driving technique very challengeable. Based on simulation prototype of in-pipe robot driven by six wheels for inspection the inner surface of seabed pipelines [3, 4], this paper focuses on the drive control system of its engineering prototype without tether, including design drive control system based on engineering requirements, hardware design of the control system, intelligent crawling control based on CAN bus and experiments.
2. Background of the robot and hardware design of the control system

2.1. Introduction of the crawling robot

In order to inspect the seabed petroleum pipelines of ShengLi Oil Field, a robot is developed. The overall length of pipeline is 20Km long, and the inner diameter of the pipe is no more than 297mm. The robot is required to work under 20 meter depth [3]. In order to locate the pipe defects, the inspection process is divided into two steps: firstly, the oil differential pressure drive type and the supersonic inspection principles are utilized to realize the on-line inspection; secondly, based on the information of first step, using the in-pipe robot completes the real-time localization inspection. This project is belonged to the second step, and the main technique indexes are:

- Normal crawling speed is 1km/h (278mm/s) and the detection speed is 0.5km/h (139mm/s);
- Driving wheels can adapt to various diameters of the pipelines automatically;
- The robot can operate in water with 2MPa pressure safely.

Based on the design indexes, motors and their drivers should be smaller and better performance. Six 80W Maxon brushless DC motors and gearheads are used to provide drive force. The six drive wheel are pushed toward inner pipeline by a locking mechanism driven by a DC motor and gearheads.

As shown in Figure 1, the in-pipe robot inspection system contains ten units, including crawler unit, drive unit, central controller unit, battery unit and ultrasonic inspect unit, etc. The drive control system receives motion commands via CAN bus and drive the robot forward and backward.

![Figure 1. Overall structure of the in-pipe crawl robot.](image1)

2.2. Hardware design of the control system

The control system based on CAN bus has the advantages of high communicating efficiency, reliable, stable, and easy to set up, which makes it feasible to the 4D (Dull, Dirty, Difficult and Dangerous) workplace like in-pipe inspection. Considering space limitation and low energy cost, an ARM processor Philips LPC2119 integrated two CAN ports is chosen as our core controller. The drive control system is shown in Figure 2.

![Figure 2. Hardware connection of control system.](image2)
As shown in Figure 2, in order to realize the locomotion control of the robot, the peripheral AD, DA, DI and DO are designed to control the seven motors (six of them for crawling and 1 for locking). Real-time current detection for the seven motors guarantees the safe operation of the motors and intelligent motion control of the robot.

3. Drive control of robot based on CAN bus

3.1. Design of CAN bus communication protocol

Technical regulation of CAN system consists of application layer, object layer, transfer layer and physical layer, and implementations have to design appropriate communication protocol to achieve compatible and secure data transfer [5]. Based on the characteristics of this robot, the made-to-order protocol was designed in order to simplify the communication. The message of CAN is designed as standard message with 8 bit data, and the source address and destination address of the message is included in the message ID.

3.1.1. Definition of message ID. There is no absolute address conception of CAN node but message ID which is used to discriminate different message. Based on the CAN2.0, structure of data frame can be defined as special meanings including information needed. The simplest way is that we can embed some information in message ID. Considering the number and stability of the communication node in this project, the information is included in the message ID as shown in Table 1. Types of message content includes: abnormal self-testing feedback (000), abnormal command execution feedback (001), pipeline fault detected (010), warning frame (011), command frame (100), normal command execution feedback (101), normal outcome feedback (110) and other special feedbacks (111); address is defined as: central controller (0000), energy supervising (0001), crawling units (0010), ultrasonic test unit (0100) and positioning unit (1000), where sender is source address and receiver is destination address.

<table>
<thead>
<tr>
<th>ID.10 ~ ID.8</th>
<th>ID.7~ ID.4</th>
<th>ID.3 ~ ID.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of message content</td>
<td>Destination address</td>
<td>Source address</td>
</tr>
</tbody>
</table>

Conflict happens when two or more nodes send message to CAN bus simultaneously. According to the regulation, CAN bus will mediate the messages based on their ID that lower numerical value of ID has higher priority level. That is why we put the type of message content at the first four bits, and the advantage is more urgent message has higher priority level whatever its source address.

3.1.2. Acceptance filtering for CAN controllers. Each CAN controller integrated in LPC2119 MCU has a register structure similar to the Philips SJA1000 and the PeliCAN library block, but the 8-bit registers of those devices have been combined in 32 bit words to allow simultaneous access in the ARM environment. The main operational difference is that the recognition of received identifiers, known in CAN terminology as acceptance filtering, has been removed from the CAN controllers and centralized in a global acceptance filter. Traditionally, the acceptance filter of SJA1000 can deal with some ruled ID or less arbitrary ID but it is hard to filter more complicate arbitrary ID. LPC2119 has a block which provides lookup for received identifiers for both the CAN Controllers. It includes a 512 x 32 (2K byte) RAM in which software maintains one to five tables of Identifiers. This RAM can contain up to 1024 standard identifiers or 512 extended identifiers, or a mixture of both types [6].

Generally, the work flow of LPC2119 acceptance filtering can be described as the following. When the Receive side of a CAN controller has received a complete identifier, it signals the acceptance filter of this fact. The acceptance filter responds to this signal, and reads the controller number, the size of the identifier, and the identifier itself from the Controller. Then it search RAM to determine whether the message should be received or ignored.
3.1.3. Definition the content of data field. Data field consists of data to be transferred with a data frame. With the single function of implementation CAN nodes in this project, limited 8 bytes is enough for command execution and data transfer, so what we should do is to code the 8 bytes. The first byte is coded as the content and the other seven bytes play as its parameters. For example, crawling units receives data “F020A042” from central controller, where “F” means crawling forward, “A” means accelerating, “042” means the acceleration and “020” means expected speed, to sum up, “F020A042” means we should accelerate the robot to crawl forward until it reaches the speed 20mm/s, and the acceleration is 42mm/s². There are totally 14 types of coding message for drive control system. When we deal with the messages, the first byte of the data field decides what we will do.

3.2. Crawling control
The fundamental function of crawling control system is communication between crawling units and central controller. Generally, crawling drive unit executes the command from central controller and reports its operational results in time. The software of drive control system is developed with ADS1.2 and mainly consists of CAN communication, locomotion control, and current detection. Figure 3 shows the workflow of drive control of the robots.

- **CAN communication**: When the system is electrified, drive control system begin self-testing, and successful self-testing result will be reported to the central controller which means the following work can run, otherwise system default. Among the following work, drive control system will keep communicating with other nodes to guarantee its teamwork.

- **Locomotion control**: Locomotion control is the key job of drive control system. Actions of the robots include locking, unlocking, micro-locking, micro-unlocking, crawling forward, crawling backward, pause crawling, stop crawling, accelerating and decelerating. The locking state of the mechanism is related to the maximum drive force, so the micro-locking is designed to insure the best locking of the mechanism. After the successful locking of the mechanism, drive control system will carry out the appropriate locomotion. Among the crawling job, soft start-up, slope speed setting, and soft stoppage are considered to make the motion more reasonable.

- **Current inspection**: Current detection for locking motor is helpful to realize the best locking gesture, protect motors, and achieve the three crawl modes, namely, unification drive mode,
grouping drive mode and independent drive mode. The three drive modes are design to make the robot adapt to the straight, curved and slope pipelines.

4. Experiments
The control characteristic of robot locomotion has been tested with experiments. Figure 4 shows the crawling unit and its drive control unit. Figure 5 shows the typical relationship between water pressure and current of unloaded crawling motor. It shows the power dissipation of crawling motor with maximum speed because of watertight devices. As shown in Figure 5, the unloaded current of crawling motor goes higher as water pressure increases. Figure 6 shows the speed control of the robot. It is clear that the required speed can be reached easily.

![Figure 4. Picture of crawling unit and its drive control unit.](image)

![Figure 5. Watertight power dissipation.](image)

![Figure 6. Speed control of crawling robot.](image)

5. Conclusion
According to special requirements of pipeline detection in oilfield, a novel crawl robot is developed, and the drive control system based on CAN bus is studied. The drive control characteristics of the robot are tested, and experimental results prove the feasibility of the presented drive control scheme.

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