EMBEDDED BASED IN-PIPE INSPECTION VEHICLE

V.Sharmiladeve, S.Raviprakash

Abstract- This paper presents a new pipeline inspection robot with a linkage type mechanical clutch, which is designed for inspection of pipelines with 110mm diameter. This robot has four powered wheel chains each of which has a mechanical adjustment. The mechanical adjustment is designed by using a parallel linkage mechanism. The performance of this robot system is based on obstacle sensors. All these are connected to the microcontroller. If any obstacle is detected in the pipeline, then it will send the information to the microcontroller and the information will be send through RF transmitter and information is collected by RF receiver. Then PIC microcontroller will immediately turn on the buzzer in the receiver unit. The buzzer sound indicates the detection of obstacle. Then distance of obstacle occurred can displayed in LCD display. The movement of robot can be controlled by using gear motor. The forward and reverse movement of robot can be controlled by using the control switches in the remote unit. The pipelines are automatically adjusted by means of mechanical clutch. The robot mechanism is designed using a parallel linkage so that it can provide two functions; the foldable characteristic and mechanical clutch. The foldable characteristic allows adaptation of the wheel mechanism to the wall inside the pipeline. The mechanical clutch function can be also realized by a parallel linkage design. This mechanical clutch is different from the typical large-sized mechanical clutch using two plates.

Keywords: mechanical clutch, obstacle sensors, microcontroller, RF transmitter and RF receiver

I. INTRODUCTION

One of the main concern affecting all buildings and industries is the maintenance required. This implies wasting of time and money necessary to prevent from future damages and to fix those already happened. Particular great problems are associated with the maintenance of pipes conduct. Numerous approach have been finished in long-ago works to build a vehicle for in-pipe inspection; they are Pig type, Wheel type, Caterpillar type, Wall-press, Walking type, Inchworm type and Screw type are available. Numerous authors have studied the problem and several numbers of commercialized robots have been reported up to now for several applications, from gas industry to sewer pipes 4 with this general problem in mind and background of previous studies, we focused our case to water pipes. One of the main issues regarding all the tubes that carry salt water is the limestone forming within them. This can reason not just occlusions in the pipes but also loss of heat exchange and of pressure. For these reasons activities for their maintenance are essential. To trim down the high resources needed for it associated with the detection of the occlusions, the destruction of the pipes, and their replacement we decided to design a versatile robot for the inspection of pipe and detection of limestone inside. One of the future developments will possibly be the capability for the robot of repairing the damages directly from inside, saving huge amount of time and money.

The robot needs to be taken out of the pipeline by using some retrieval function. The concept of clutch is a good solution for realization of the retrieval function. There are two types of clutch; mechanical clutch and magnetic clutch. Usually, the mechanical clutch guarantees a strong power, but it is usually large-sized, heavy, and has a complex structure. On the contrary, the magnetic clutch is relatively small-sized, light, and has a simple structure, but it has a limitation in power. However, commonly such magnetic type clutch mechanisms are still too large and complex to apply to small-sized robots with less than 100mm diameter. Also the magnetic type has limitation in firm gripping. In this paper, we introduce a new differential-drive type pipeline inspection robot with a compact-sized linkage-type mechanical clutch for 100 mm pipelines. The robot mechanism is designed using a parallel linkage so that it can provide two functions; the foldable characteristic and mechanical clutch. The foldable characteristic allows adaptation of the wheel mechanism to the wall inside the pipeline. The mechanical clutch function can be also realized by a parallel linkage design. This mechanical clutch is different from the typical large-sized mechanical clutch using two plates. Section II introduces the characteristics of the robot system. The geometric analysis is presented in section III. We show the validity of this robot system by both simulation and results in section IV. Lastly, we draw conclusion.

II. ROBOTIC SYSTEM

A. Robot unit

The robot system consists of a control box and a robot device. Using the modularity, the robot device is separable from the control box. The robot device consists of a main body, three wheel chains, and three clutch wheel parts as shown in Fig. 1. The length of robot is 80mm and the exterior diameter is 100mm. Realization of the retrieval function through the mechanical linkage design is meaningful, because it removes the disadvantages of magnetic brakes such as slippage, limited power transmission, and limited size. This robot mechanism can be operated in two different modes;

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driving mode and retrieval mode. The driving mode represents that the robot is in motion, and the retrieval mode implies the state of retrieving the robot to the entrance location.

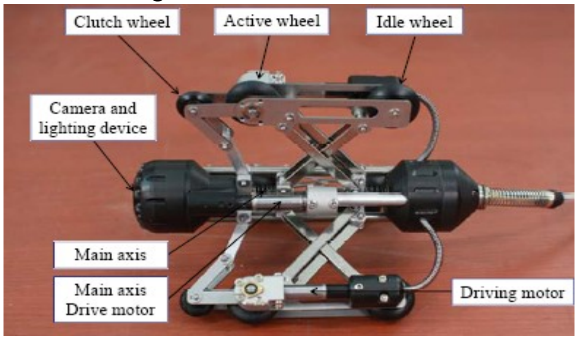

Fig. 1.The developed robot.

For realization of both modes, we drive the robot device using three wheel drive motors and one main axis drive motor as shown in Fig. 1. Using the three wheel drive motors, we can control the forward and backward movement and the steering motion at the elbow. Switching from one mode to another can be made by using the main axis drive motor.

B. *Robot body*

The main body consists of two nuts, two key sliders, two compression springs, and an axis drive motor. The nuts transfer power to each side of the main axis, the key slider slides along a groove of the nut and it is connected to the linkage of the wheel chain. The compression spring adapts to change of the outer diameter of the wheel chain. This design allows a foldable characteristic of the robot body. The main axis consists of a spur gear in the middle, a left-handed screw, and a right-handed screw. The power of the main axis drive motor is transferred to the main axis through the spur gear. The change of mode can be made by the main axis drive motor. Rotation of the main axis yields the translational motion of the screws. That results in displacement of the nuts as well as the key sliders at the same time

C. *The wheel chain and clutch part*

The left end of the main axis is connected to the clutch wheel part at the distal location of the screw. The wheel chain consists of a parallel linkage, a wheel drive motor (6)), an active wheel, and an idle wheel. As shown in Fig. 1, each wheel chain is linked to the clutch part. The wheel drive motor drives the active wheel through a bevel gear power transmission. The clutch part consists of a clutch wheel and a linkage that connects the clutch wheel to the main axis. The clutch wheel is also an idle wheel. As shown in Fig. 3, the wheel chain is linked to the main axis by using four- and five-bar mechanisms. A parallelogram mechanism is employed to keep a horizontal posture of the wheel chain. The motion of the wheel chain is coupled to the motion of the clutch wheel through a four-bar that connects the main axis to the upper part of the wheel chain.

D. *Driving and retrieval modes of the robot device*

When the robot is being inserted into a pipeline, the outer diameter of the robot is adjusted by using the main axis drive motor. Fig. 2(a) denotes the state that the robot is being inserted into the pipeline in the driving mode, where two nuts are located in the middle. When the wheel of the robot passes through an irregular surface or a small bumper inside the pipeline, an external force is applied to the wheel chain. As a result, the key sliders connected to the wheel chain behave like Fig. 2(b). Compression springs located at both sides of the main axis play the role of shock absorption. When the robot goes over the bumper part, the key slider goes back to the state of Fig. 2(a) due to the restoring force of the compression spring.

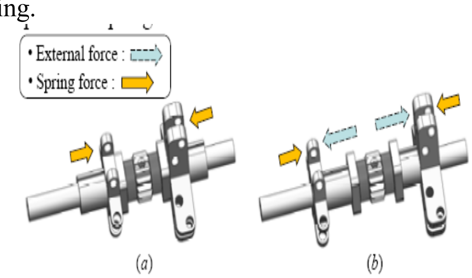

Fig. 2. The driving mode.

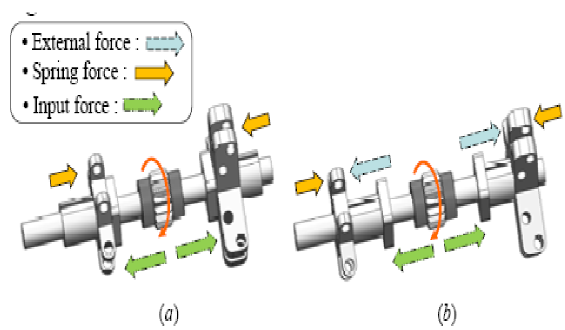

Fig. 3. The retrieval mode.

Fig. 3 shows the retrieval mode. Activating the main axis drive motor, the initial configuration of the main axis is set up as this configuration where the two nuts are farther apart. As a result, the driving wheels of the three wheel chains lose contact with the wall of the pipeline. On the contrary, the passive wheel of each wheel chain gains a contact with the wall. Thus, the robot can be retrieved from the pipeline by pulling a wire connected to the rear side of the robot.

III. GEOMETRIC MODEL

One of the most important issues in the design of a driving vehicle is how to obtain the traction force enough to pull instrumentation as well as the vehicle itself. Particularly in

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straight up pipelines, it is desirable to keep adequate wall pressing forces in order to ensure sufficient footing armed forces. Extreme forces may disperse power and be in danger of destructive the robot. On the opposing inadequate armed forces may cause the robot to fall down. On the condition that the wheel does not slip on the pipeline surface, the grip force is comparative to the friction coefficient and the pressing force between the wheel and the pipeline surface, and the friction coefficient depends on the material of wheel and the surface condition of pipelines. In accumulation, the relation system of the vehicle should minimize the variation of traction force caused by variation of channel diameters. Therefore, a leg system has to rally the following three requirements. At first, it should be possible to push against the pipeline wall with adequate imperative forces. In the next, the imperative force should not show significant change during navigation in order to provide stable traction force and supple locomotion. At final, the system should be easy and small in size to occupy minimal space inside the pipelines. For example, the motivating automobile of MRINSPECT III has three wheeled legs circumferentially spaced 120 degree apart on the main shaft of the vehicle. Fig. 4 illustrates the kinematic diagram of the wheeled leg mechanism of MRINSPECT III. The mechanism employs a pantograph mechanism with a sliding base that permits the natural folding and unfolding of the leg. Here, *l* is the length of link, _ means the folding angle of the link measured by the rotary potentiometer, *K* denote the spring even, *h* represents the distance of the center of the wheel from the base. *w F* denotes the wall pressing force, *x A* and *y A* are the forces acting on the link by the spring, *x* is the displacement of the downhill base. In the anticipated mechanism as the wheel is pressed they just contract or expand along the radial direction. It is a very advantageous feature because undesirable distortion forces are not exerted on the robot when the robot goes over obstacles. First the relation between *h* and *x* can be obtained as

$$h = 2x\tan\theta = 2\sqrt{l^2 - x^2} \qquad (1)$$

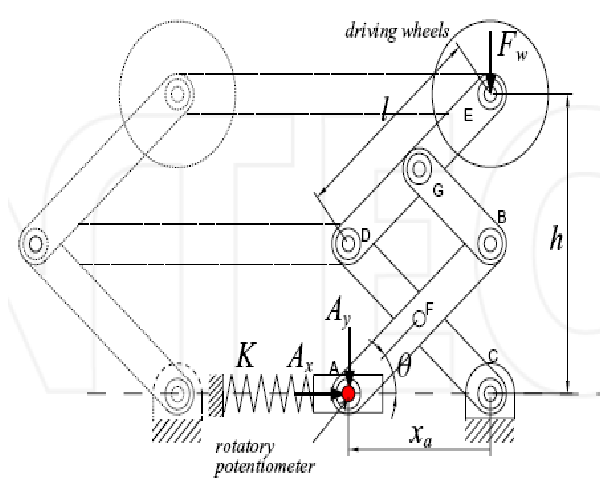

Fig 4. Wheeled leg mechanism of MRINSPECT III

When the link rotates by _ , the radial force *x A* and the axial force *A* acting on the spring are written by

$$A_x = 2F_w \tan\theta, A_y = 0 \qquad (2)$$

By using Eqs. (1) And (2), Eq. (3) will be derived

$$A_x = \frac{2F_w x}{2\sqrt{l^2 - x^2}} = 4F_w \frac{l^2 - h^2/4}{h} \qquad (3)$$

Now, let us differentiate Eq. (3) and derive spring constant *K* at the operating point *d x* (8inch) which satisfies

$$A_x = K(x - x_0) \qquad (4)$$

Where *o x* denotes the initial dislocation. Next, we have

$$K = \frac{2F_w}{\sqrt{l^2 - x_{d2}}} \frac{l^2}{l^2 - x_{d2}}, \qquad (5)$$

$$x_0 = \frac{x_{d^3}}{l^2} \qquad (6)$$

Eq. (5) represents linear zed spring steady and Eq. (6) denotes the early span of the spiral. Mutually are the essential equations for computing the wall pressing forces. By adjusting *K* and *o x* properly, the wall pressing force with minimum variation can be obtained.Based on the above position analysis, the behaviour of the proposed kinematic model is tested through a numerical simulation using Mat lab. Fig. 5 shows the simulation result of the wheel mechanism.

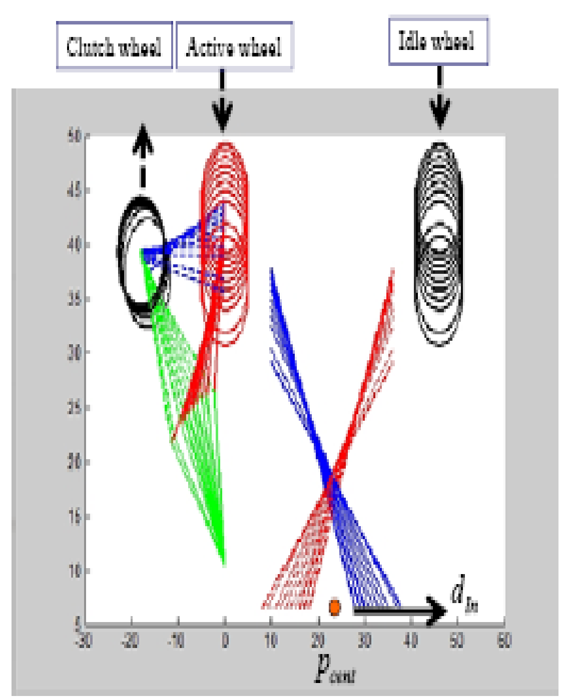

Fig 5. The result of kinematic simulation

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IV. DESIGN PROCESS

A. Controller

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics distribution. The given name PIC originally referred to "Peripheral Interface Controller". PICs are well-liked with developers and hobbyists alike due to their small cost, wide ease of use, big user base, wide-ranging collection of function notes, ease of use of small cost or free expansion tools, and serial programming (and re-programming with flash memory) capability. The robot controller consists of a control box and a robot device. The robot control is executed by a serial communication. In this system, we use two MCUs (PIC 16F877a). One MCU calculates the angular velocity of the joystick interface and the linear velocity of the robot. The other MCU calculates the motor speed by producing a PWM signal. It can control all of the Micro DC motors. All the motor drives and MCU are integrated in the control box. The view of the pipeline is provided to the user by using a Micro CMOS camera mounted in front of the robot body. This module makes it possible to inspect the condition inside the pipeline. The robot device equipped with a camera and a lighting device of LED source.

B. The robot device

The motors are embedded in the motor box of the wheel mechanism. The peak torque is 17.5 mNm. The Maxon re 6 and GP 6A gear head are chosen for this robot. Table I describes the specification of the motor and the gear head.

TABLE I
SPECIFICATION OF THE MOTOR (MAXON RE 6) AND THE GEARHEAD (GP 6A)

Specification	**Value**
Nominal voltage	6 v
Nominal speed	5320 rpm
Max. Continuous torque	0.321 mNm
Max. Continuous current	0.118 A
Gear head reduction	221:1
Gear head max. Continuous torque	30 mNm

Table II shows the specification of the robot. The length of the robot module is 80mm and the exterior diameter of the robot body changes from 90mm up to 110mm. The total length of the robot device including the camera and the lighting device is 122mm. And the weight of the robot is 189g. In this paper, a pipeline with diameter of 100 mm is employed as a test bed.

TABLE II
SPECIFICATION OF THE ROBOT

Specification	Tbot-100
Weight of the robot module	189g
Motor diameter	6mm
Length of the robot module	80mm
Total length of the robot	122mm
Exterior diameter	90-110mm
Linear speed	14cm/sec

V. RESULTS

A pipeline consisting of 6 elbows is employed as a test bed. The elbow is a commercial product. The total length of the test bed is 3m. Fig. 6 shows the operator terminal for the experimentation and Fig. 7 shows the simulation result for the forward movement of the robot. Fig. 8 shows the obstacle detection in pipeline and wireless transmission can be successfully as shown in the Fig. 9.

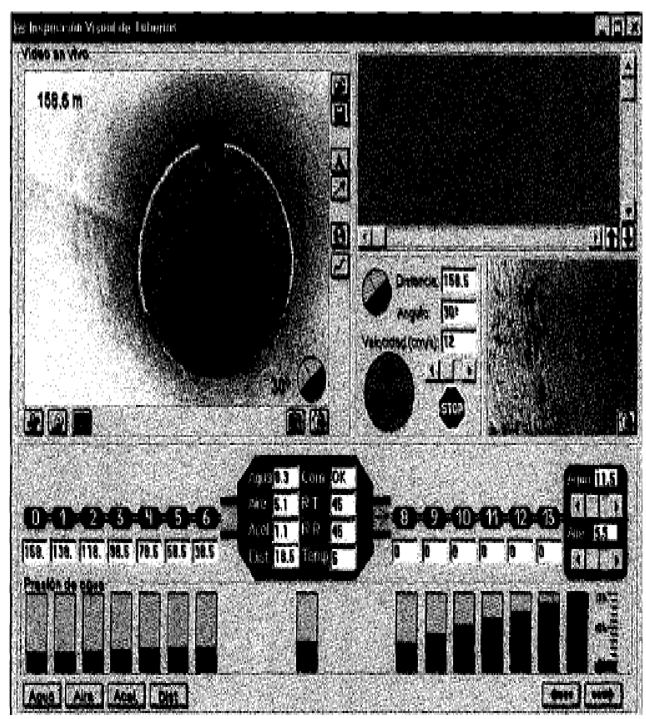

Fig. 6. Operator Terminal

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Thus, the performance of the proposed robot system could be verified through this experimentation. The attached video clip shows the experimental result.

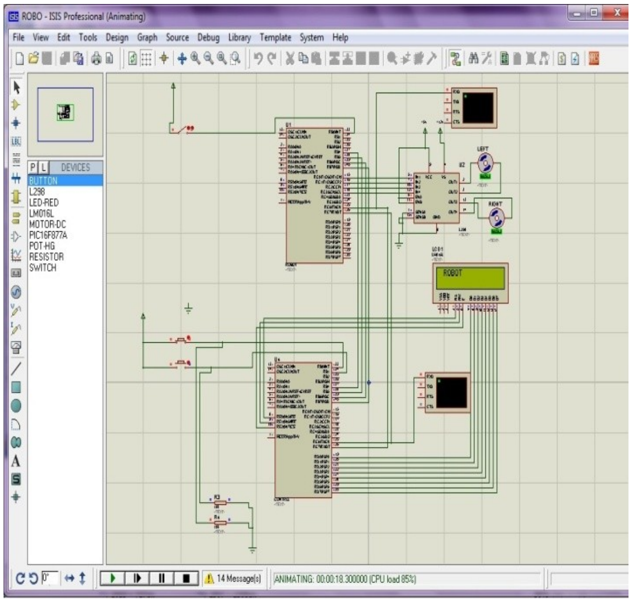


Fig. 7. Forward movement of robot

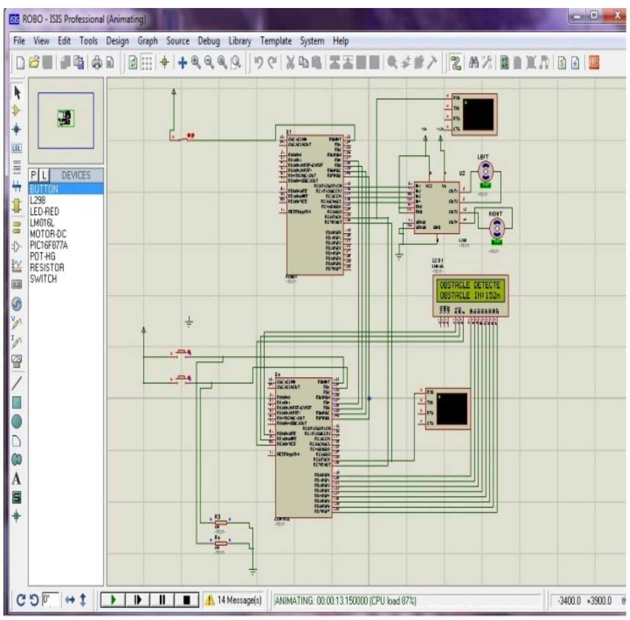
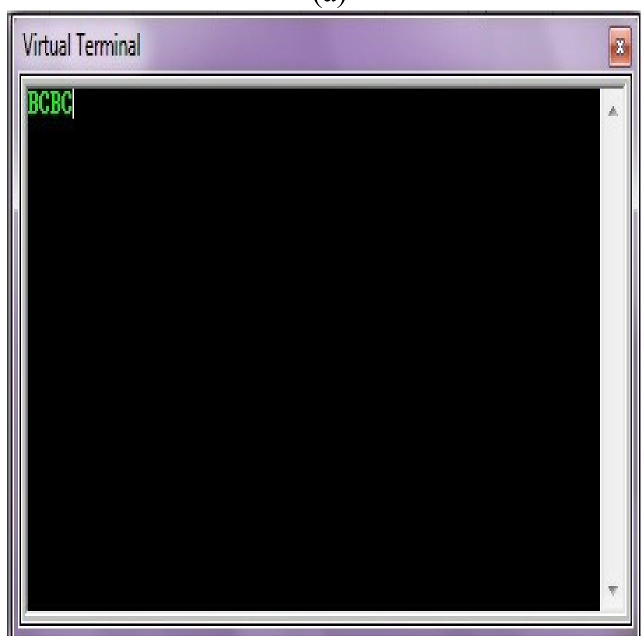


Fig. 8. The simulation result: obstacle detection in the pipeline.

(a)



(b)

Fig. 9. Wireless transmission has shown using virtual terminal. (a) Forward movement, (b) Reverse movement

VI. CONCLUSIONS AND FUTURE WORKS

We developed a new differential-drive type pipeline inspection robot with a linkage-type mechanical clutch for inspecting 100 mm pipelines. The behavior of the proposed kinematic model is tested through a numerical simulation. The performance of the proposed pipeline inspection robot system was verified through a variety of experiment under a test-bed environment. As the future work, optimal parameterization for the compression spring, gear ratio of the main axis drive motor, and kinematic dimension will be conducted.

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