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An Evaluation of the Hybrid Locomotion System for Robots Exploring Pipes

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Abstract

In order to create a robot platform that is both sturdy and adaptable, scientists have been working on hybrid locomotion over the last five years. This has allowed them to significantly improve upon earlier in-pipe inspection robots. The purpose of this research is to identify and categorize various hybrid robots according to the means by which they move around. One of the hybrid propulsion systems is a caterpillar-like shape that presses against walls. categories: wheeled wall-pressed and wheeled wall-pressing screw. Because each hybrid locomotion system is adapted to a certain environment, it is possible that they cannot be used in other places. This report aims to provide insights into the latest advancements in in-pipe robot inspection technology. The wall-pushed sort of primary locomotion was the most often employed way in in-pipe robot development, according to the researchers. Many of the prototypes have the capability to traverse branches that are the same diameter as the main pipe. As a benefit, the caterpillar's wheel allows it to crawl over branches and other barriers without experiencing motion singularity.

1. Introduction

The oil and gas business, the power plant industry, and the sewage system all use in-pipe inspection robots. Defects, fissures, and internal erosion caused by deterioration, creep, overheating, corrosion, and other factors are inspected with these robots. Over the last two decades, several robots designed specifically for in-pipe inspection have been developed. Types include those with wheels, those with legs, those with snakes, those with inchworms, those with screws, and those with PIGs. Each robot has been built with unique design criteria in mind, and as a result, it may not function well in another setting. As a result, the inspection robot platform can only be used for particular pipe layouts due to its limited single locomotion mechanism. In order to further improve the resilience and adaptability of their creations, robot cists have recently begun implementing a combination of two or more locomotion systems into pipe inspection robots. The inspection robot's hybrid locomotion mechanism allows it to adapt to and go through pipes of varying shapes and sizes. Each mode of transportation has its own set of benefits and Drawbacks, especially when it comes to adapting to different environments and tasks. The capacity to go between branches more easily is a major selling point for wheeled types, particularly those with differential drive [1]. The benefits of a caterpillar type include the ability to go through rough terrain and around obstructions in the pipe [2]. High movement and branching pipes are a common design goal for the snake and legged types [3, 6]. The ability of inchworm-like robots to navigate round conduits is a distinct advantage [7], [8]. The construction of most screw types is straightforward, making them simple to use [9]. Many different hybrid locomotion systems have been introduced to inspection robots during the last five years. These systems may be broken down into three distinct groups, as illustrated in Fig. 1: the caterpillar wall-pressed type, the wheeled wall-pressed type, and the wheeled wall-pressing screw type. In Section II, we provide a quick rundown of the various hybrid categories. All the different hybrid kinds discussed in Section II are summarized and compared in Section III, both in terms of their functioning mechanism and their overall performance. Section IV concludes the findings and analysis.

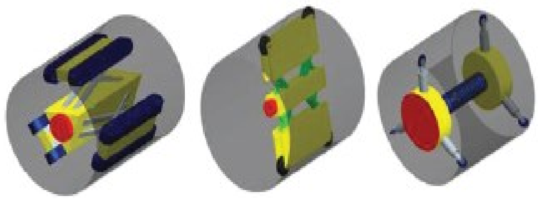


Fig.1. (a) Caterpillar wall-pressed type; (b) Wheeled wall-pressed type; (c) Wheeled wall pressing screw type

2. Hybrid Locomotion

There are several different types of single-propulsion mechanisms, including wheels, caterpillars, snakes, legs, inchworms, screws, and PIGs. Depending on the constraints of the in-pipe environment, each mode of mobility has distinct benefits and drawbacks. The goal of combining several locomotion systems is to eliminate the drawbacks of the individual systems. System as cutting-edge alternative propulsion mechanism is of paramount significance. The hybrid locomotion system addresses not only the restrictions imposed by the set propulsion mechanism, but also the peculiarities of pipes, such as variations in diameter, curvature, slope, and so on.

2.1. Caterpillar wall-pressed type

The robot's frame is secured to the wall via caterpillar track. Good forward and reverse traction is provided by the robot's caterpillar wheels. The robot is able to effortlessly navigate uneven ground and curves because to the combination of these two systems, which enable it to adapt to a wide range of pipeline diameters. These robots typically have three major components: such the main frame, the caterpillar wheel, and the adjustable linkage system. The wall-pressed caterpillar type is shown structurally in Figure 2.

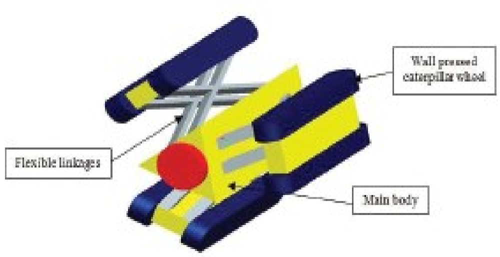


Figure 2: The pressed-wall construction of a caterpillar

FAMPER [10] has four caterpillar tracks and extended link systems for checking out pipes of up to 150 mm in diameter. Because of its adaptability, it can navigate broken pipes and get around obstructions. Attached is a Caterpillar track to a rectangular central body platform suspended by four detachable links (157 mm to 127 mm in length). Sustained operation is ensured in spite of varying pipeline conditions thanks to a suspension system comprising springs and flexible linkages. To allow the robot to go over bends and branches in the pipe, the speeds of the individual caterpillars may be adjusted separately. The prototype showed remarkable mobility in a test bed consisting of a 45° elbow, a 90° elbow, and a T-branch. Some of the wheels on a regular wall-pressed robot lost contact while rotating due to a motion singularity issue. However, FAMPER has a unique mechanism for adaptability and obstacle avoidance. The wheels of a caterpillar robot are slanted at an angle of 5 degrees with regard to the main body so that the vehicle can level itself. All of the caterpillar's wheels can now make touch with the ground. In addition, the ability to turn and maneuver around obstacles is bolstered by a segmented caterpillar mechanism that can be bent. The caterpillar mechanism is also equipped with shrinkable shaft to give support for the caterpillar frame. The robot's inspection range is increased, and its overall length is cut by up to half, thanks to this shaft. Similar movement strategies, albeit significantly reorganized, were used by Y. S. Kwon et al. [11]. The three caterpillar wheels are spaced 120 degrees apart and attached to the triangular main body through a pair of four-bar connection mechanisms.
Because of its linkage design, the caterpillar wheel can accommodate variations in pipe diameter. The robot has an 80 mm outside diameter and a 100 mm maximum size. Using silicon for the wheel's outer surface increases the wheel's grip and propulsion, building on the caterpillar's already impressive surface contact retention. The wheels of a caterpillar are each autonomously managed. The robot may be propelled in any direction by use of the caterpillar wheels. To prevent motion singularity, which causes one caterpillar wheel to lose contact at the turning point, it is recommended to use two robot modules. The front module is pushed beyond the turning point by the compression force stored in the spring that is linked between the modules. The expansion force

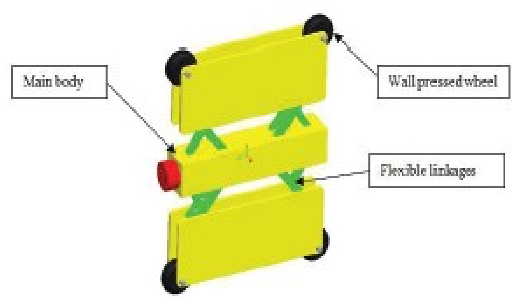
held in the spring, on the other hand, is what pulls the back module. The 532g robot is able to go from a horizontal to a vertical route because of its lightweight construction. The prototype functioned as intended during testing in an acrylic pipeline with many cast iron elbows and T-branches, similar to pipeline type 80 seen in Korea and Japan.

Caterpillar wheels and wall press locomotion are also used in PAROYS-II [12]. There are two sets of Caterpillar wheels; each set 120 degrees from the central module. The wheels of the caterpillar may be individually maneuvered. However, the pantograph mechanism of PAROYS-II may be extended and contracted by a leads screw in the central module, allowing it to accommodate pipe diameters from 400 mm to 700 mm. Its front and back tracks are each made out of a segmented module, making its caterpillar wheels another another unique characteristic. The front track is linked to a remote-controlled servomotor mounted on the back track. A rotatable front track keeps the wheels in touch with the ground, no matter how bumpy the terrain. PAROYS-II is able to effectively turn in a curved pipe because of the revolute connection that joins the track module and pantograph mechanism. These two upgrades to the PAROYS-II caterpillar wheels greatly improve the robot's overall performance in challenging environments.

2.2. Wheeled wall-pressed type

The differential drive mechanism of the wheeled type gives excellent steering capabilities, which is particularly useful while crossing pipe branching the performance of a typical legged wall press robot is improved by adding this function. This kind of hybrid locomotion is mechanically identical to the preceding type with the exception of the less tire traction means less force is needed to move the vehicle. A basic robot like this has its uses for certain applications because of its design. In addition, wheels are more practical than a caterpillar track for fast, mobile transportation. Wheeled wall-pressed robots, like the one seen in Figure 3, are made up of a main body, a wheel, and a flexible linkage system.

Y.S. Kwon et al. [14] used a sophisticated robot with two wheels and a chain for inspecting pressed pipe walls. The centre module space is often taken up by the robot's wheels, which, for a typical wall-pressed robot, means at least three chains. The folding mechanism is used to accommodate the pipe's changing diameter, much as in previous wall-pressed robots. This robot can examine pipes between 80 and 100mm in diameter. The chains of wheels are mounted at an angle of 180 degrees with support from a folding mechanism that runs parallel to the main body, and the wheels themselves are in touch with the wall. This novel strategy makes room for additional cameras to be attached to the back and front of the body. The robot's ability to move in a screw motion means it can maneuver in closer to the pipe, allowing the side camera to get a better look. The term "detecting mode" describes this process. To achieve this motion, the wheels must be set in a reverse orientation. The capacity to turn is provided by manipulating the wheel chains such that they all point in the same direction. Because of these two actions, wheel types are superior to caterpillar wheels. This locomotion mechanism just needs the same speed to spin the robot in either direction, hence it requires less steering control than the other wall-pressed robot. If there is no steering angle, the robot will operate in the driving mode, where it will proceed in a straight line. Experiments have shown that this novel method can solve the motion singularity issue with a single module.



3. Wall-pressed structure on wheels [14]

The identical locomotion system, albeit with a modular approach, was constructed by E. Darien et al. [15]. The robot's seven parts—two driving modules, two clamping modules, two payload modules, and a central control module—each serve a distinct purpose. Module for rotation. This apparatus is intended for use with pipes ranging in diameter from 63mm to 125mm. This robot's ability to make a precise mitered turn is its defining characteristic. As a result, the module has a rounded form. Although it travels up and down the pipe, this robot moves laterally to avoid debris and dirt at the pipe's base.

The robot is kept in the pipe's middle plane by the bending modules. The first two bending modules and

the final two bending modules exert the torque. They come with motors and springs to create the clamping torque necessary for use. H. O. Lim et al. [16] presented a pair of wheeled, modular robots that push against walls. The robot has a body that links the front leg system to the back leg system. Three legs make up each system, and they're spaced 120 degrees apart utilizing worm gears. The legs are linked together, and their joints may be opened and closed with the help of a remote-controlled servomotor. This makes it possible for the robot to accommodate pipe diameters ranging from 125 mm to 180 mm. The DC motor turns the wheel, and the legs push against the pipe wall to propel the robot forward. The robot is able to twist thanks to a DC motor fitted in its body.
A CCD camera mounted in the foreleg system captures images of pipe problems.

2.3. Wheeled wall pressing screw type

Three modes of movement have been merged into one wheeled, wall-pressing, screw-type robot. The robot's wheel function reduces the amount of force required to turn a standard screw in a pipe. Rotator and stator are often required to provide screw-type motion. This wheeled, wall-pressing, screw-type robot's internal construction is seen in Figure 4. The most appealing aspect of this type of robot is it requires at least one actuator to move.

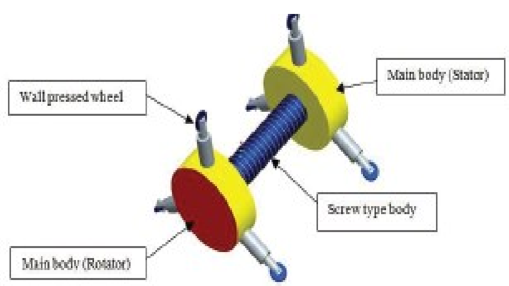


Figure 4: Schematic of the Wheeled Wall Pressing Screw [18]

An adaptable squirm-like robot powered by a single motor was developed by Y. H. Zhang et al. [17]. This robot is one of a kind since it can also be utilized online, where the stress of constant operation is negligible. The robot is propelled by a fluid current. The magnetic wheel devices on this robot's legs and guide rod allow it to adjust to changes in pipeline diameter with ease. The robot's body is supported by the magnetic wheels, which also assist the robot to stick to the metal wall. The permanent magnet wheel receives electromagnetic force from the brake mounted in the leg. The robot's ice cream cone shape also helps it achieve better turning performance. It has a scoop-like form on the left and a cone-like body on the right. The ice cream scoop's body has a flexible helical axle and a gear nut that together provide a screw driver mechanism. The helical axle drove the right body forward while the left body was attached to the pipe wall. The left body may be moved to the right by switching the motor's direction. The robot is navigated with the help of a guiding head. It comprises of rods that are either free or subject to control, and it is mounted in the right body to allow for a certain turning angle. These rods, which may be adjusted, are linked to the left side of the body. The guiding head will rotate in an L-shaped elbow in the same way as the elbow itself rotates. The helical axle may be bent such that it is perpendicular to the axis of rotation of the guiding head. The robot follows the identical steps in T-branches, but its left side pulls the controlled rods to make a 45° angle. To lessen the load on the actuator, the team lead by A. Kakogawa [18] included a screw driver mechanism system into their cutting-edge wheeled wall pressing invention. To service both straight and curved pipes, this robot was developed. Because of this, screw-type locomotion is all that is necessary to traverse the curved pipe. Because of their mobility and quickness, wheeled types are preferred.
In addition, the lack of wheels on the screw driver type allows for less friction to be exerted against the wall. Since the normal force exerted by the wall may be used to counteract the force of gravity acting on the body, the wall-pressing technique is the optimal locomotion mechanism for climbing.

3. Discussion

The most common sort of in-pipe inspection robot has been the wall-pressed variety throughout the previous five years. It has been merged with various methods of movement to boost its capacity for particular situations. Both wheeling wall-pressed and stationary wall-pressed caterpillars are effective against the tree limbs. Caterpillar wall-pressed, on the other hand, excels in greater wall contact area than competing branches. The robot was able to avoid motion singularity thanks in large part to the linking system that was included throughout much of the design. However, Y.S. Kwon et al.'s wheeled wall-pressed robot has shown its use by successfully executing a screw action. Using a side camera, this motion is ideal for getting a closer look at the pipe. In a curved pipe environment, the third hybrid system excels. Pipelines and branches of similar diameters are both within the inspection capabilities of these robots. However, none of these have been evaluated simultaneously in a variety of pipe and branch diameters. Expanding the diameter of a pipe of the wall-pressed kind from small to large is simple, but the reverse is more challenging. At the beginning of a narrower conduit, the robot might get stalled. If the main pipe is 300 mm in diameter and the branches are 80 mm in diameter, there will be a serious difficulty. Table 1 summarizes the benefits and drawbacks of using a hybrid locomotion in-pipe robot. The relative performance of the various robot categories is compared in detail in Table 2.

4. Conclusion

Many different kinds of single locomotion systems have been developed and tried out during the last two decades. These modes of transportation have their uses, but they are becoming more obsolete as technology advances. The progress of in-pipe robots is reviewed in this article. The standard method of in-pipe robot movement has been hybridized by researchers. Systems to enhance functionality. Experimental findings demonstrate that most robots, when using a hybrid system, are able to solve the motion singularity issue, particularly when traversing branching and curved pipelines. Furthermore, the hybrid system enhances the robot's adaptability in terms of movement and the capacity to capture images. A robot of hybrid type may have numerous mobility modes built into its design. None of these prototypes, however, have been tested in a real-world setting where there is an abrupt change in pipe diameter at branches.

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