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Pipe Inspection Robot

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Abstract

The main purpose of this study is to be able to identify the faults, corrosion and surfaces in pipes that are difficult to reach in buildings, structures, infrastructure works and sewers. Technically, this robot has been developed to be able to move not only within a single pipe but also within various different diameter pipes. In addition, the robot can easily reach the places that are not very suitable for health. There are also some prohibited areas of human access, such as nuclear power plants, refineries, natural gas pipelines and exhaust systems. The robot can also reach the point that people can not enter due to human dimensions. In other words, faults that occur these places can be critical for human life. Therefore, the robot can receive, diagnose and process the data in these areas.
In this study, kinematic and dynamic analyses of the pipe inspection robot are extracted. Kinematic calculations are used to determine robot motion trajectory and also to analyze robot motion on straight and curved pipelines surfaces. Dynamic equations of the robot such as friction force, drag force and mass effect are analyzed in order to find the minimum motor momentum in vertical, horizontal and curved pipelines. A prototype robot is designed according to these calculations in Solid works CAD environment. The motion simulation and experimental study are carried out with the help of this robot prototype successfully.

Key words: Pipe, inspection, crawler robot, diagnoses.

1. Introduction

Inspection robots are used for maintenance, construction, construction supervision, security, industrial system supervision and industrial process supervision. The access of a human operator to these types of systems can be difficult due to the environment in which the human health can be jeopardized. These robots have been developed along with the development of technology since they have certain characteristics for difficult environments and surfaces conditions. For example, sewage systems can be summarized as sewer systems, regions with high radial rate in nuclear power plants, various power generation plants, petrochemical storage tanks. It is important that the interface is designed to process the appropriate data during the robot programming process by considering the standards. The basic problem of the robot is the friction force required to climb to vertical surfaces and the weight the robot [1-3].
In this study, a pipe inspector robot is designed in order to diagnose faults of sewage systems. The robot is tested with the lightest material available to reduce the weight. The frictional force of the surface can not be increased. Therefore, the highest friction force of tires is desired . A rubber from a material is used in order to increase friction force. The robot is controlled by using a wireless network.

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2. Materials and Design

The designed robot must be prepared under certain circumstances. The first one is how to move in a pipe. If a pipe was produced from a metal material, the robot could move smoothly with a magnetic walking tool. But the project is made from a standard plastic pipe. The robot should be able to remain immovable in the vertical position in the pipe due to its main idea. The robot should be able to move without encountering a problem in the curved sections of the pipe. It should be able to move vertically in the pipe and it must defeat the force of friction. Thanks to the camera connected to it, it should be possible to transfer the picture to a computer by Wireless connection.

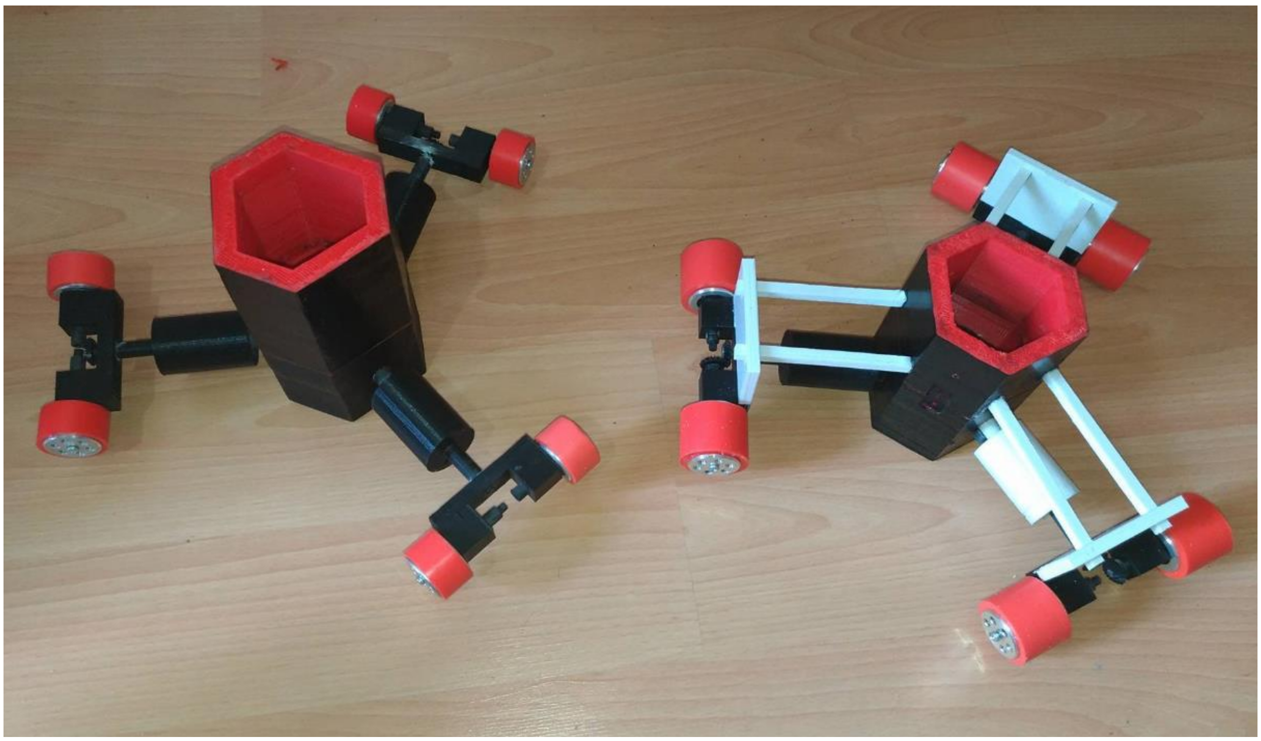

Figure 1. Body parts of pipe inspector robot

In Fig. 1, the designed and manufactured robot can be seen. The climbing method used in the pipe detective robot is the friction force. The maximum friction force will increase the holding rate of the robot. However, too much friction force will affect the power of the motor to be used.

Only the lateral force is affected by the robotic friction. ABS 3D printer material is preferred for this. Thus, the robustness of the robot is greatly increased. The wheels on the holding surface are specially selected to increase the frictional forces. Shore 20 special hardened wheels are used to increase surface area for this robot

In the production of the robot, the design is adopted as the design and adaptation to the variable diameter pipes and movement in these pipes. For this purpose, a special mechanism has been developed for the tip of the milling gear to which the rotational motion of the motor is transferred.

This mechanism provides both rotational and suspension motion. The springs determined to have properties after the measurements are calculated to provide rotational motion by means of a gear wedge, which is added to the design while assisting in this suspension movement [4].

The support rods were thrown towards the axle bars of the wheel of the robot to hold the robot's wheels straight and at the same level in the pipe. This system, which is used by taking a little restriction of the variable diameter feature of the robot, increases the robustness of the robot.

Torque is transmitted to the gears produced by the DC motor, so that the robot moves within the pipe. In Fig 2., placing of the DC motor to the robot is showed. In Table 1, specifications of designed and manufactured robot are given.

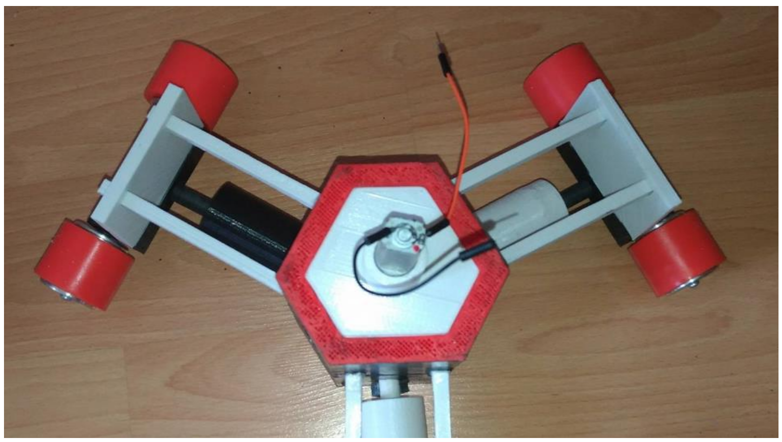

Figure 2. Placing of the DC motor to the robot

Table 1. Robot specifications

Specifications	Value
Operation voltage	12 V
Holding Current	1.2A at 12V
Revolution Per Minute	35 RPM
Holding torque	4 Nm

3. Control Algorithms

Raspberry Pi model 3 was used for the control card. There are 40 pins on board which works with 5V-2A values. By using the card, Wi-Fi and Bluetooth modules that support communication protocols like SPI, I2C, it is also very convenient to control in real time. At the same time, there is also a camera plug-in option, which can instantly transfer the acquired image to the user's computer. These control cards use Linux-based Raspbian software as the operating system. It can be used as a computer interface via USB and HDMI inputs on the card. Raspbian, which mainly uses the Python software language, requires a startup software to open the Cayenne MyDevices interface. This software will enable Raspberry Pi, which works when the power supply is turned on, as well as the Cayenne interface.

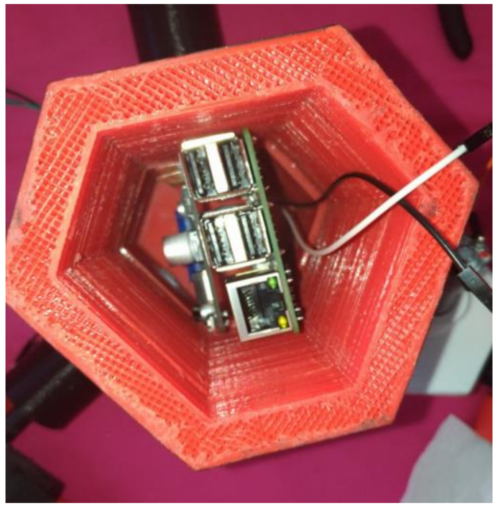

Figure 3. Assembling of Raspberry Pi Model 3

The Raspberry Pi Model 3 is placed into robot as seen in Fig. 3. The robot's DC motor is controlled by internet or Bluetooth protocol. The preferred method are performed in real-time. By using real-time control, the robot can react instantly to commands. Because it is controlled over the Internet, it also provides remote access and control. This method also allows us the use of the camera as an option. Thanks to the Cayenne MyDevices interface, this real-time control is easily accomplished. User interface of Cayenne is showed in Fig. 4.

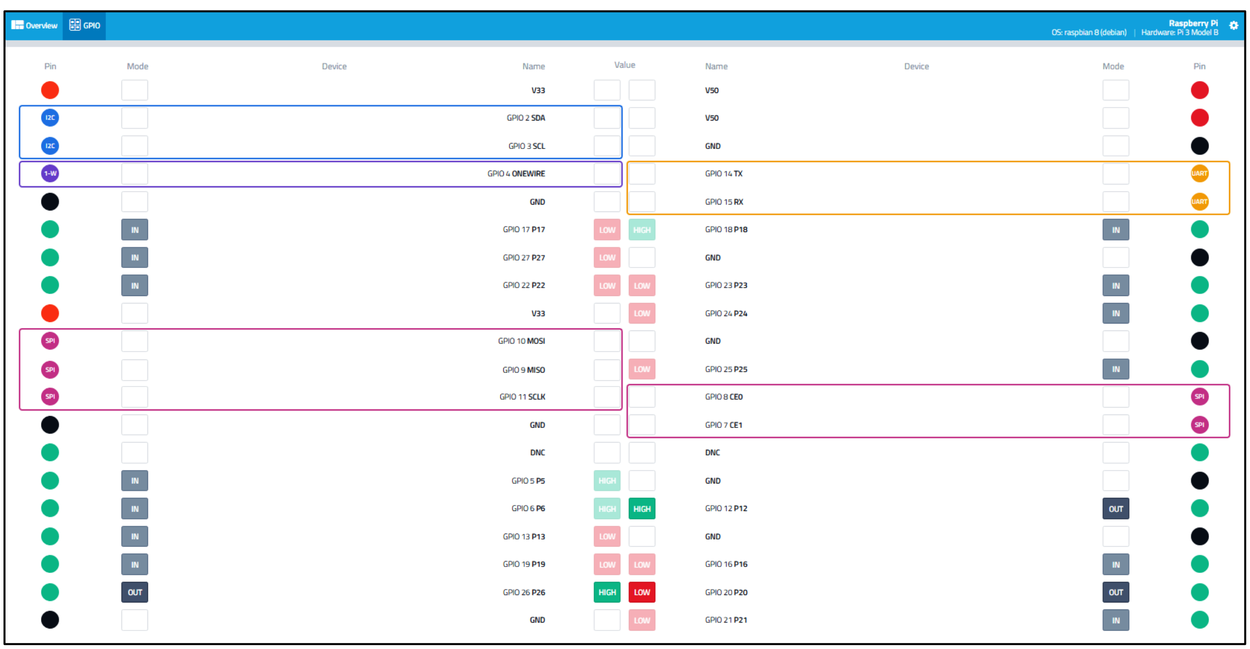

Figure 4. User interface of Cayenne

4. Mathematical Modelling

The most important parameters to design a robot are weight, size, spring stiffness and the engine torque. The torque and the spring forces must be calculated in order to allow the robot to move while the robot is climbing from the vertical pipe.

Figure 5. Pipe inspection robot

The weakest point of the robot, which is important in terms of holding to the surface with the friction force, is the weight. ABS is a very light and durable material used in many parts including the body. When all the robot parts and electronic parts are included in the CAD software, the weight of the robot is 2878 grams. The robot is designed as 3 symmetrical parts at 120-degree angle and 4 pieces of special rubber tires with Shore 20 hardness degree are used for each part [5]. The weight of each symmetrical part is determined to be 959.3 grams. Each piece has 4 wheels in the design level, that is carrying 239.83 grams by itself. The minimum frictional force required to hold the robot on a steep surface at this point is 28,233 Newton. The friction force per wheel is 2352,765 Newton. The frictional forces applied below these values is insufficient to hold the robot upright. When these frictional forces is increased, the motive power start to decrease. The optimum level is the closest to the above values [6].

In order to ensure that the robot climbs straight to the pipe when considering a single motion arm, the spring wheel system, T_{ω} torque should have been calculated in Eq. (1-5).

$$N_t \cos\alpha \geq N_m sin\alpha \tag{1}$$

The static friction force, *f*, is the normal force on the inner wall of the tube and the force induced by the static friction coefficient. In the event of inadequate static friction between the inside of the pipe and the robot wheels, the robot can even slip down with positive torque. For this reason, the condition for stable motion of the robot is as follows [4];

$$f \geq Ntcos\alpha + Nmsin\alpha \tag{2}$$

During the vertical motion of the robot, the force resulting from the spring force F_s and the normal force F_n is the same. So, f can be written as;

$$f = \mu kd \tag{3}$$

The minimum motor torque required to climb up is obtained for the vertical pipe as follows;

$$RMgtan\alpha \leq Tm \leq R(\mu kdcosec\alpha - Mgcot\alpha) \tag{4}$$

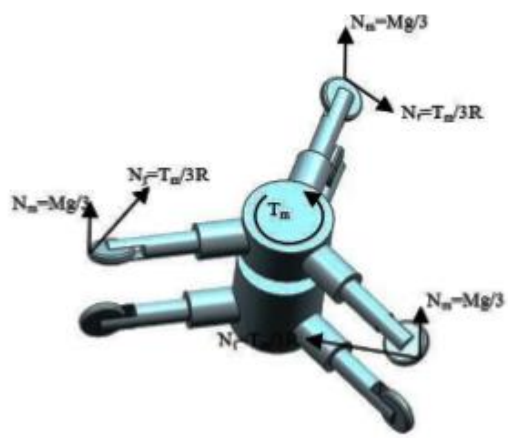

Figure 6. The friction force of pipe inspector robot [4]

Higher motor torque is required for a greater value of the friction coefficient. For lower loads, the minimum motor torque required to climb the pipeline will be less. The torque directions of the robot is illustrated in Fig. 6.

As a result, the dynamic motion equation of the robot can be expressed as in Eq. (5):

$$\ddot{\theta} = \frac{T_m - bsina\frac{\rho C_{drag}A}{2}\{(b+r)\dot{\theta}\sin(a)+v\}^2 - n\mu bF_n - (M_{motor} + M_{Rotor} + nm)(b+r)gtan(a)}{\left(M_{motor} + M_{Rotor} + nm + n\frac{I_{wx}}{r^2}\right)((b+r)\tan(a))^2 + \left(m + \frac{I_{wz}}{r^2}\right)nb^2 + I_{hp}} \tag{5}$$

In Table 1, necessary parameters for obtaining the dynamic motion equations is given.

Table 1. Abbreviations for the dynamic motion equations

Abbreviations	Definition	Abbreviations	Definition
M	Mass of the Robot Kg	m	Mass of wheel Kg
g	Gravitational	b	Distance from centre of hull

	acceleration = 9.81 m/sec2		to the central axis of wheel M
T_m	Torque produce by Motor Nm	r	Wheel radius M
T_w	Torque on wheel Nm	A	Effective cross-sectional area of Robot m2
N_t	Force on pipe wall produce by motor torque N	C_{drag}	Coefficient of Drag
N_m	Force on pipe interior due to gravity N	R	Motor Resistance Ohm
α	Wheel tilt angle Degree	L	Motor Inductance H
f	Static friction force N	I_{hp}	Polar Moment of Inertia of Rotor Kg.m2
μ	Coefficient of friction between wheel and pipe interior -	I_{wx}	Wheel Moment of Inertia about x-axis Kg.m2
R	Radius of pipe Mm	I_{wz}	Wheel Moment of Inertia about z-axis Kg.m2
M_{hull}	Mass of hull Kg	I_m	Motor Moment of Inertia Kg.m2
M_{motor}	Mass of motor Kg	μ	Fluid Dynamic Viscosity Kg/m.s
g	Gravitational Acceleration m/sec2	v	Downward Velocity of the Fluid m/sec
K_f	Damping Constant N.m.s	ρ	Fluid Density Kg/m3

5. Results and Discussion

In this study, a robot design and implementation was realized under variable diameter pipes conditions. A suspension system is reduced to a diameter of 320 mm and a diameter of 30 mm as optimal design. The Raspberry Pi Model 3 developer card and the Cayenne MyDevices interface were used to perform real-time control of a DC motor, so the robot was moved inside the pipe. In addition, a special mechanism was used that can perform both rotational motion and suspension motion. As a result of study, a robot is designed to diagnose broken, cracks, rusty places of pipe. A successful and optimal design is performed.

Figure 7. The prototype of pipe inspector robot

Conclusions

This paper presents an adaptive robot for variable pipe diameter in order to detect crack, rotten, rusty zones in pipes. Therefore a design and torque calculations is performed. It is desired that robot can pass through the pipe easily and smoothly and so spring wheel system is used. The Raspberry Pi Model 3 is used to control DC motors remotely. A successful design and implementation is carried out in this study. As a future study, it is aimed to use a camera to diagnose the pipe. In addition, Fuzzy Logic and PID (proportional integral derivative) controller is desired to use for controlling DC motor.

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