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## Adjustable magnetic force system for climbing robot

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**Abstract.** Wall climbing robots with the magnetic adhesion force have been used for various inspection tasks to increase the performance of inspection and human safety, for example on a metal bridge, tank, pipe etc. The important element of the robot mobility is the adhesion force between the magnet on the robot and the ferromagnetic surfaces. The amount of the force depends on the thickness of the surface and the air gap distance between the magnet and the surface. An insufficient adhesion force can cause the robot to slip from the surface, while the excessive amount of adhesion force would require higher driving torque. In order to maintain the adhesion force at the appropriate level, the feedback control technique was applied to control the adhesion force by adjusting the distance between the magnets and the surface. In the proposed system, the distance between the magnets and the surface can be varied by a screw drive mechanism actuated by a stepper motor. The PID controller was implemented on a micro controller. The load cell was used as a sensor to measure the adhesion force. This signal was fed back and compared with the reference force signal. In the experiment, the force control system was installed on the magnetic wheel robot in order to test the mobility of the robot on different surface thickness. By using the proposed force control system, the magnetic adhesion force can be regulated at the desired level.

### 1. Introduction

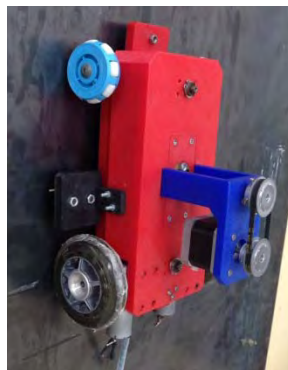
At present, the climbing inspection robot have been studied and employ in various applications. Since the robot can operate in hostile environments which can affect the safety and health of the human operators, for example high position, air pollution, unreachable space etc., using the inspection robot can increase reduce the danger for the operators [1,2,3,4]. Most of the industrial structures and machines are made from the ferromagnetic materials; it is beneficial to use the magnetic adhesion robot such as magnetic wheel robots[4,5]. Even though, the climbing robot can have adhesion from direct contact between the magnetic wheel and the surface; however, the contact area between the magnetic wheel and the surface is very small. If the magnetic wheel does not contact with the surface, the amount of adhesion force reduces rapidly and may not enough to maintain the robot to stay on the ferromagnetic surface. In order to solve this problem, [6,7]the magnetic force from the body is a simple approach to increase the adhesion for the robot. The magnetic force is distributed, but the amount of adhesive force is lower than that of the magnetic wheel. Therefore, using magnetic wheels

and /or the attachment of the magnetic on the body of the robot depends on the characteristic of the surface. The difference in term of geometry and the thickness of the surface can cause the different amount of the adhesion force. This is an important issue for the climbing robot. The adhesion force can be reduced from the decreasing of the surface thickness. Consequently, the climbing robot can loss the contact from the surface, if the adhesion force is inadequate. On the other hand, over magnitude of adhesion force can increase the load for the driving motor which is inefficient. In appropriate amount of the adhesion force affect the motion control of the climbing robot. Thus, maintain the adhesion force at the desired level is an important aspect for the climbing robot design.

Development of the climbing robot with magnetic force adjustment system to maintain the magnetic adhesion force is the main focus of this study. In this work, the PID controller is used to control the adhesion force based on the feedback signal form the load cell. The magnetic adhesion force can be adjusted by changing the distance between the attached magnetic and the surface. Thus, the adhesion force of the robot can be maintained under the variation of the surface thickness.

## 2. Robot Design

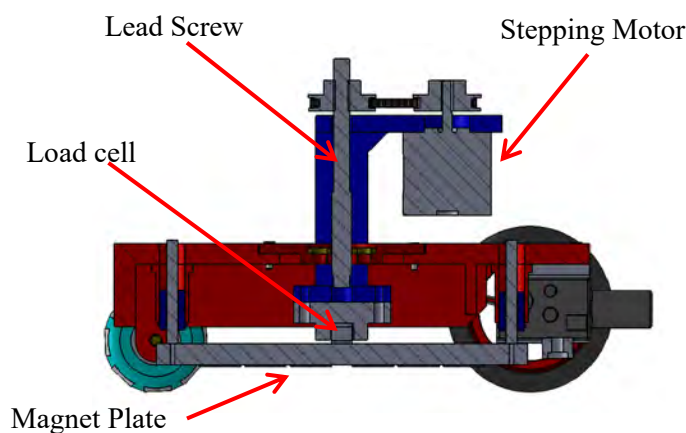
In this study, the two-wheel differential drive robot is designed and installed with the magnetic adhesion force system. The locomotion of the robot consists of two wheels driven by the DC motors and one supporting wheel as shown in Figure 1. The PLA plastic chassis of the robot is made from the 3D printer. The over al dimension of the robot is  $11 \times 15 \times 28$  cm with the weight of 2.4 kg. as shown in Figure 1.



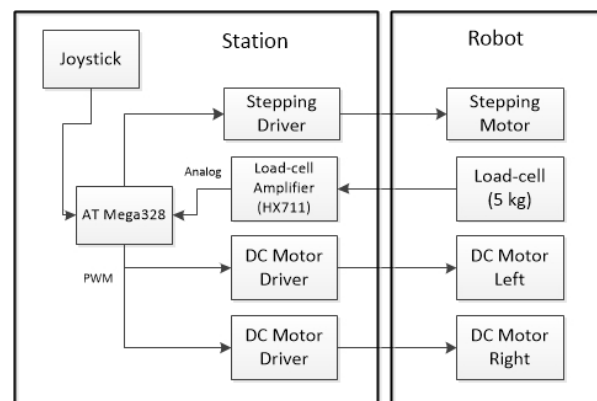
**Figure 1.** Designed robot.



**Figure 2.** Array of Neodymium magnet on plate.



**Figure 3.** Magnet force adjusting system.



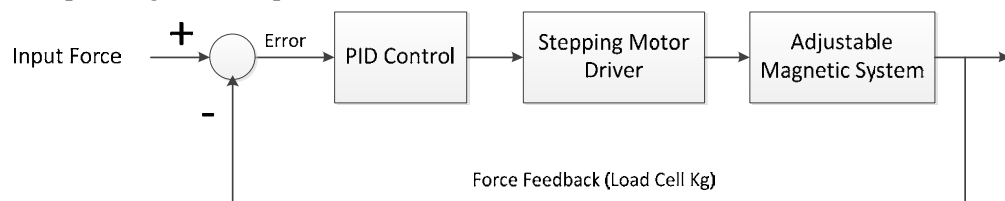
**Figure 4.** Overview of the architecture of the robot.

For the adhesion of the robot, the neodymium magnets with the size of  $40 \times 20 \times 5$  mm are installed under the robot. The change of the distance between the array of magnets and the surface can be achieved by the lead screw driven the stepping motor with  $1.8 \text{ deg/step}$  through the timing belt. The pitch of the screw is 1 mm. The precision of this adjustment system is of 5 micrometer. The magnetic force can be measure for the feedback signal by using the load cell located between the screw and the array of the magnet. The adhesion force adjusting system is shown in Figure 3.

The control station of the climbing robot is connected to the robot through the cable. The control elements and sensors are shown in Figure 4. The control station consists of the main processor *AtMega328*, motor driver system and the amplify circuit for the load cell. The joy stick is used for the operator to control robot from the station.

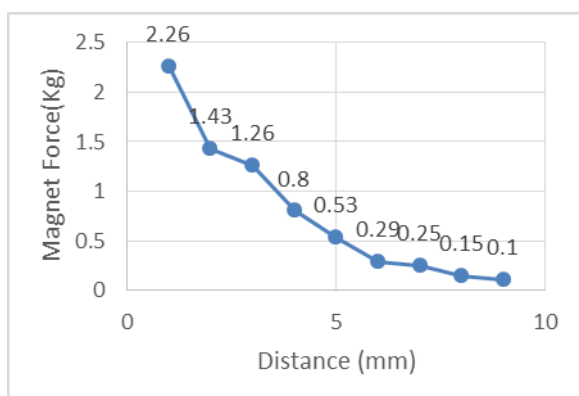
### 3. Magnetic Force Control

The feedback control of the magnetic adhesion adjusting system can be shown in Figure 5. The load cell is used as a sensor to measure the force signal and provides the feedback signal for the control. The error is the difference between the reference signal which is the required magnetic force signal and the actual force measured by the load cell. The error signal is sent to the PID controller. Then, the control signal from the controller is fed to the stepping motor driver system. The output from the stepping motor driver system is used to adjustable magnetic system to set the elevation of the array magnetic corresponding to the required adhesion force.

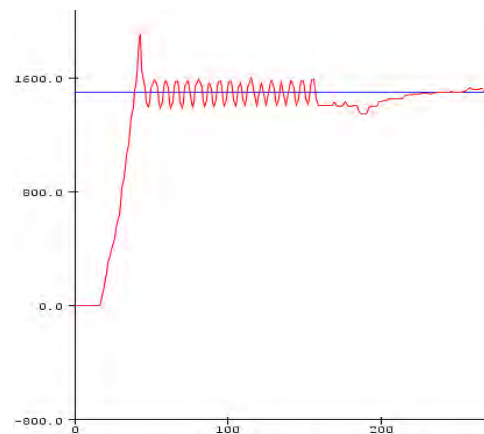


**Figure 5.** Schematic diagram of the PID control.

### 4. Experiments Results



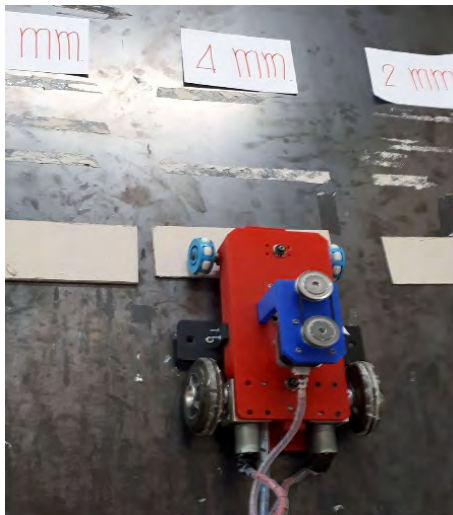
**Figure 6.** The relationship between the magnetic force and the distance



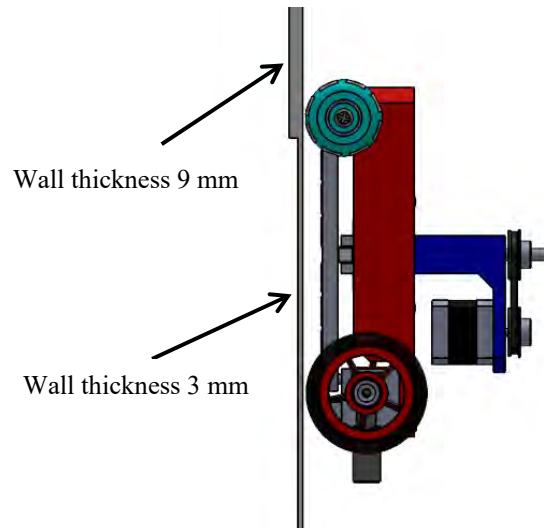
**Figure 7.** The plot of the magnetic adhesion force response under the PID controller.

In order to determine the adhesion force provided by the magnet bars, the magnetic force of each magnet is measured at different distance from 1 mm to 11 mm. The relationship between the magnetic force and the distance is shown in Figure 6. The range of the measured magnetic force is from 0.07 kg to 2.26 kg. Thus, in this work, the minimum and maximum distance between the magnet array and the surface are 7 mm. and 11 mm. respectively. The 12 bars of the magnets is used which has the corresponding range of the adhesion from 1.4 kg to 7.2 kg.

The experiment is divided into two parts. First, the experiment was conduct to determine the set of the gain of the PID controller. Thus, three different reference force signal corresponding to 500 g were applied with the adhesion adjusting system. The output force for each condition was measured and plot as shown in Figure 7. The gain of the PID controller were tuned manually as  $K_p = 0.1$ ,  $K_i = 0.015$ ,  $K_d = 0.002$  with the sampling time of 100 ms. According to the selected gain, the settling time is 0.5 s.

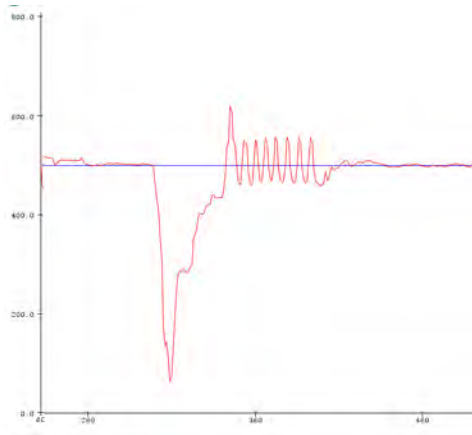


**Figure 8.** Non-Ferromagnetic obstacle test

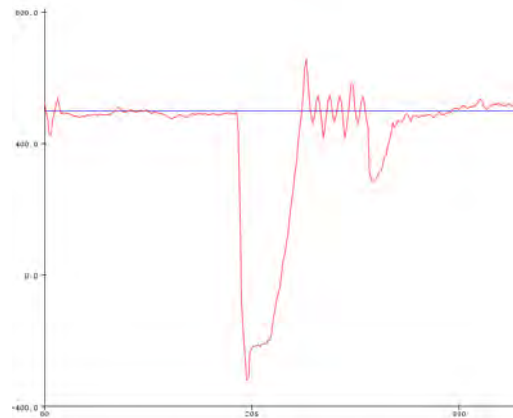


**Figure 9.** Robot test on ferromagnetic wall with different thickness

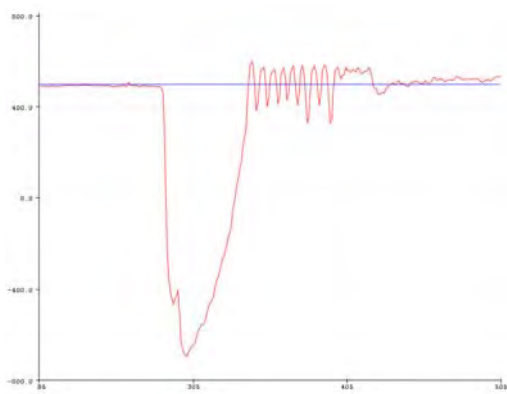
Second, the experiment was carried out to investigate and evaluate the performance of the magnetic adhesion adjusting system. The adjusting system was test by moving the robot with constant speed of 3 cm/s straight forward on the ferromagnetic wall which has the different thickness shown in Figure 8 and different obstacle object shown in Figure 9. The three different size of the obstacle thickness of the wall are 2, 4 and 6 mm and the thicknesses of the surface were 3 mm and 9 mm respectively. The results of the experiment showed that the climbing robot could maintain the constant speed while passing all sizes of the obstacle and surface thickness as shown in Figure 10, 11, 12 and Figure 13. Thus, it is clear that the magnetic adhesion system with the selected controller gains can provided the desired adhesion for the climbing robot.



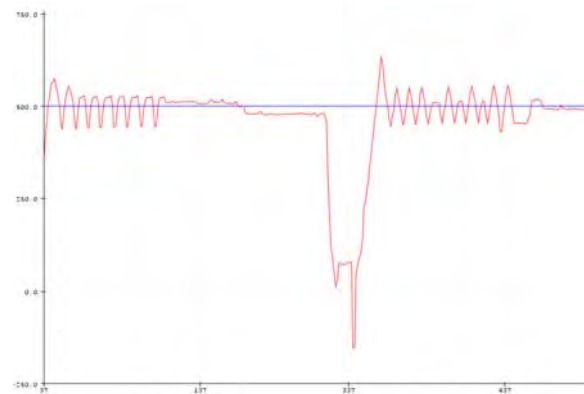
**Figure 10.** The plot of the force response affected by the obstacle with the size of 2 mm.



**Figure 11.** The plot of the force response affected by the obstacle with the size of 4 mm.



**Figure 12.** The plot of the force response affected by the obstacle with the size of 6 mm.



**Figure 13.** The plot of the force response when the robot move from the surface with the thickness of 3 mm to the surface with thickness of 9 mm.

## 5. Conclusion

According to the results of this study, the design magnetic adhesion adjusting system can be successfully employ to maintain the magnetic adhesion at the desired level under different surface thickness and the size of obstacle objects. However, the noise from the magnet bars can affect the accuracy of the load cell measurement. In order to employ the adhesion force adjusting system practically, the reduction of the dimension and weight of the magnetic adhesion force system need to be concerned for further study.

## References

- [1] Briones L, Bustamante P and Serna M A 1994 *Proc. Int. Conf. on Robotics and Automation (San Diego)* vol 2 (California: United States) p 1409-1414
- [2] Kalra L P, Gu J and Meng M 2006 *Proc. Int. Conf. on Robotics and Biomimetics(Kunming)* vol 1 (China) p 1523-1528
- [3] Boonyaprapasorn A, Maneewarn T and Thung-Od K 2014 *Proc. Int. Conf. on Applied Robotics for the Power Industry (Foz do Iguassu)* vol 1 (Brazil) p 1-6
- [4] Fabien T, Francois P, Wolfgang F, Gilles C, Francesco M, Roland M and Roland S 2010 *Proc. Int. Conf. on Applied Robotics for the Power Industry (Montreal)* vol 1 (QC: Canada) p 1-2
- [5] Yuanming Z, Tony D, Kais A and Ian L 2010 *Proc. Int. Conf. on Mechatronics and Automation (Xi'an)* vol 1 (China) p 1393-1398
- [6] Faruq Howlader M O and Sattar T P 2015 *Proc. Int. Conf. on Computer Science and Electronic Engineering Conference (Colchester)* vol 1 (United Kingdom) p 105-110
- [7] Silva M F, Barbosa R S and Oliveira L C 2012 *United Kingdom. Journal of Robotics.* 2012 **906545**