



PRESSURE CONTROL OF WALL CLIMBING ROBOT USING PID CONTROLLER

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ABSTRACT

Nowadays, wall climbing robot plays a vital role in the rapid growth of technology development. Potential applications are quite numerous, such as inspection, maintenance and cleaning operations of civil infrastructures which involve a high number of dangerous manual operations and represent a danger even for skilled workers. In view of the present situation of hazardous inspection environment, wall-climbing robot generally divided into adhesion part, movement part and control part. The rough surface wall environment is a challenging problem for adhesion. To address the problem, a negative pressure adhesion mechanism with adaptive control based on proportional integral derivative (PID) controller is proposed. The minimum revolving speed (RPM) that robot can adhere on the wall reliably is verified by the experiment conducted. The ducted fan model is analyzed using SolidWorks Flow Simulation and the relationship between the motor speed and the adhesion force is described in detail. The feasibility of robot which adopts pressure adhesion adaptive control method using PID is demonstrated in MATLAB Simulink. Last but not least, the simulations with gap interference were done and its results are discussed respectively.

Keywords: wall climbing robot, adhesion, pressure, PID controller.

INTRODUCTION

Wall climbing robots are useful devices that can be adopted in a variety of applications, such as bridge monitor tasks. These robots are generally employed in places where direct access by a human operator is very expensive or very dangerous due to the presence of a hostile environment. To be success to operate, the robot must consist of necessary systems like control systems, power supplies, sensor devices, manipulators and software [1-3]. Up till now, a lot of research has been devoted to wall climbing robots and various types of experimental models have already been proposed. The two major issues in the design of wall climbing robots are their locomotion and adhesion methods.

With respect to the locomotion type, three types of movement are often considered: the crawler type, the wheeled type and the legged type. In this project, a wheeled type climbing robot which can move relatively faster than others with continuous motion is chosen.

Regarding to the adhesion method, generally it can be classified into four types, e.g. magnetic devices, propulsive force, vacuum suction techniques and bionic theory. In these kinds of adhesion methods, magnetic suction is easy to achieved [1],[2], but ponderous in organization and consumptive in power, moreover, its application fields are limited badly—ferrous surfaces only. Propulsive force suction system demands complicated thrust and locomotion control [3], [4], which makes it difficult to move smartly, therefore it can be hardly seen in practical applications. Those based on bionic theory are relatively novel, and they are being studied broadly [5-8], most of them are in fundamental study phase now, there is a long way to go to apply the knowledge into practical use [9]. Wall climbing robots using vacuum suction techniques have merits such as simpleness and credible suction ability, so

they have always been focus of the study domain, as well as in this project.

SYSTEM DESIGN

The core of the developed wall climbing robot system is a powerful ducted fan with vacuum motor designed to offer maximum static thrust at its highest efficiency. In order to easily drive the climbing robot up 90° surface with sufficient torque, two pairs of wheels and high power micro gear motors are adopted. Following are the major parts of the wall climbing robot which had been built according to the requirements:

Locomotion part

The wheel mechanism is employed, because of its simple control, uncomplicated design and can move rapidly. The movement command sent from RC transmitter is transferred to the RC receiver implemented on the robot. The command is then being decomposed and converted to electrical signal to drive 4 high power micro gear motors. With the aid of four-wheel drive, the robot able to enhance its climbing ability, in order to move forward and backward, turn left and right smoothly on the wall.

Control part

Arduino Uno, the core control component plays an important role in processing all kinds of signal. For example, amylases motion commands into high power micro gear motors driven signal, transforming RC communication signal and more. The communication distance using RC transmitter & receiver can reach 50-1000m which fulfills the requirement.



Adhesion part

The negative pressure adhesion mechanism used in this robot mainly achieved by using a brushless DC motor ducted fan. As the motor spins at high speed, the blades inside ducted fan are driven to rotate coaxially by the motor's output torque. Then the robot can adhere on the wall surface, due to an air discharge and a differential pressure formed between the external atmospheric pressure and the sealed chamber pressure.

This is the contribution of the project. The robot must adapt itself in a various types of surfaces. For example smooth and rough surface. When in smooth surface, the robot can operate smoothly due to ducted fan generate force excellent sealing performance. However, too much force will cause the robot unable to move. Therefore, the PID controller to control the adhesion force in both smooth and rough surfaces is proposed in order to avoid the sudden drop of adhesion force.

In MATLAB Simulink test, the important input criterion is the pressure of the ducted fan. Hence, the parameter is crucial to take control. It is obviously seen that differences in pressure are affected by the ducted fan revolving speed. Therefore, the ducted fan speed relation with pressure of seal chamber is the fundamental issue to be tackled. From the perspective of ducted fan and sealed chamber, pressure system can be classified into two. First is zero pressure process, which means that the condition when the ducted fan clearing the air of sealed cavity. Second is pressure rise process. Here, rate of leaking air is lower than rate of exhaust. This is to ensure the pressures can slowly rises until stability is achieved. Due to the both pressure, the system mathematical model is equal to one-order inertia model with pure time delay. Hence, the overall system model can be expressed as:

$$G(s) = \frac{G}{Ts + 1} e^{-\tau s}$$

G is the gain total

T is constant time of inertia τ is time delay total

PID CONTROLLER

PID controller is one of the most popular controllers commonly used in control engineering. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. Proportional mode will remove oscillations in the system; Integral mode will help minimize error to zero by raising the control signal. Meanwhile, Derivative mode result in quick reaction on the change of system controller input thus will enhance the system stability (e.g. see Table-1).

PID can be tuned by using either Manual tuning method or Ziegler- Nichols tuning method. The reason for tuning the P, I and D parameter is to get the desired control response for the system. Therefore, the rise time, settling time, steady state error and

overshoot are among the basic requirement that need to be considered in order to achieve the goal.

In manual tuning method, parameters Kp, Ki and Kd are adjusted by observing the response of the system response. The parameters will be adjusted until the system gets the desired response. The tuning method is described as below:

1. Set both Ki and Kd to zero.
2. Kp is continuously increase until oscillation at the output shows. Next, Kp is set by diving the value for a type of response called quarter amplitude decay.
3. Ki value is raise so that correction on the offset can be made. When tuning Ki, be careful because over tune Ki will cause the system not stable.
4. Next, increase Kd. The Kd is raised till the loop obtain is acceptable to obtain the reference after load disturbance. But, be careful because exceed Kd cause overshoot and excessive response.

Table-1. Effect in increasing coefficient.

Parameter	Rise Time	Overshoot	Settling Time	Steady State Error	Stability
Kp	Decrease	Increase	Small change	Decrease	Deteriorate
Ki	Decrease	Increase	Increase	Eliminate	Deteriorate
Kd	Small change	Decrease	Decrease	No Effect	Improves

On the other hand, Ziegler- Nichols tuning method is a technique that was implemented by Nathaniel B. Nichols and John G. Ziegler. The tuning technique for this method is described below:

1. Both Ki and Kd is set as zero.
2. Increase Proportional gain till obtain ultimate gain, Ku. Ultimate gain, Ku is where the oscillation of the output of loop begins.
3. From the ultimate gain, Ku, obtain the oscillation period at a constant amplitude oscillation.
4. Value of ultimate gain, Ku and oscillation period, Pu is used to calculate the Ki, Kp and Kd (e.g. see Figure-1 and Table-2).

Table-2. PID Ziegler-Nicholas tuning method.

Controller	Kp	Ki	Kd
PI	0.45Ku	1.2Kp/Pu	-
PID	0.6Ku	2Kp/Pu	KpPu/8

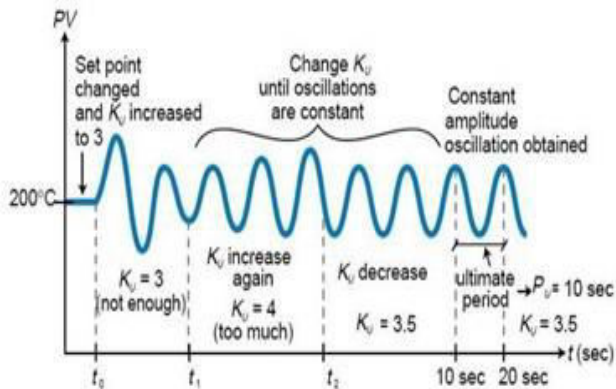


Figure-1. Ziegler- Nichols tuning method.

RESULT & DISCUSSION

Simulation in SolidWorks

The relationship between revolving speed and adhesion force is determined by means of Flow Simulation using SolidWorks software. From the experiment conducted on the wall climbing robot which had been built, the minimum motor speed required for the robot to adhere on the wall reliably is about 5500rpm. In SolidWorks Flow Simulation, the ducted fan model is meshed, boundary conditions are given and air is selected as the material type used to run the solver with input 5500rpm. Figure-2 shows the minimum and maximum adhesion force when the propeller spins at a constant speed of 5500rpm.

Details of specs and information of the used ducted fan are shown in Table-3.

Table-3. Ducted fan simulation in SolidWorks.

Diameter	70mm
Height	35mm
Speed	3900kV
Min. Speed Required to stick on the wall	5500rpm

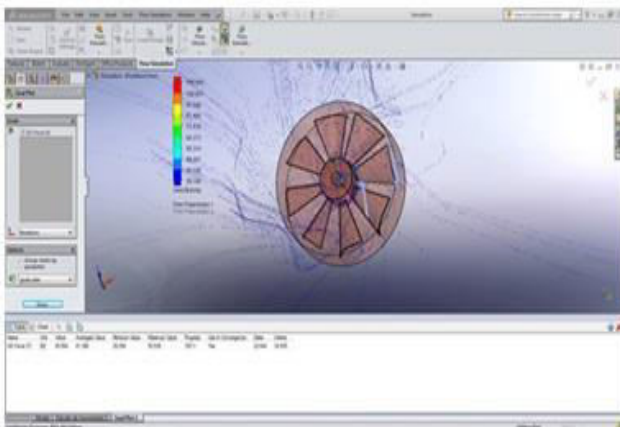


Figure-2. SolidWorks flow simulation.

Table-4. Simulation result in SolidWorks.

Name	Unit	Value	Min. Value	Max. Value	Delta	Criteria
GG Force (Y)	N	45.56	28.29	50.94	22.54	34.94

Based on the result tabulated in Table-4, the maximum adhesion force obtained from the experiment is approximately 51 N. This value is then used to run the MATLAB Simulink, especially simulation with the gap interference. However, the adhesion force in the whole climbing process should always greater than the minimum value, approximate 28N. This is due to the chamber pressure leakage issue which will directly affect the climbing robot's safety when it encounters any crack on the wall surfaces.

MATLAB simulation

The Simulink design using PI controller is shown in Figure-3. Several blocks are used to design this Simulink including step block, transfer function block, sum block, gain block, integrator block, transport delay block and scope block. The force input of ducted fan is set as 51 N. In the Simulink, the value of Proportional (P) is set as 9 and the value of Integral (I) as 1. The simulation is then run and the result is shown in Figure-4.

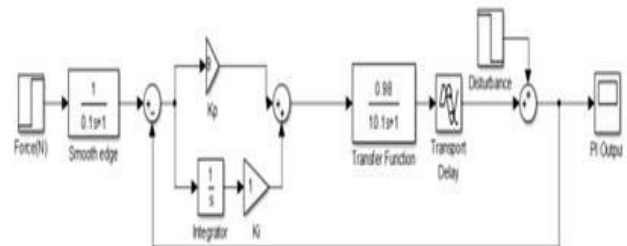


Figure-3. Simulink of ducted fan controlled by PI controller with disturbance.



Figure-4. Graph of adhesion force (N) against time(s) of PI and PID using manual tuning method.



Based on the results in Figure-5, it can be seen during of the time of gap interference occur, the adhesion force will definitely reduce. Consequently, the revolving speed is constantly advancing so that the adhesion force can be compensate. On the same period of time, PI controller will automatically fixed the decreasing adhesion force to the actual adhesion force. The reason to maintain the actual force is to ensure the wall climbing robot did not fall. Based on the simulation result, after the adhesion force reduce 7N, it costs 4sec for the wall climbing robot to return to the steady-state and the adhesion force active accelerate to 51 N again.

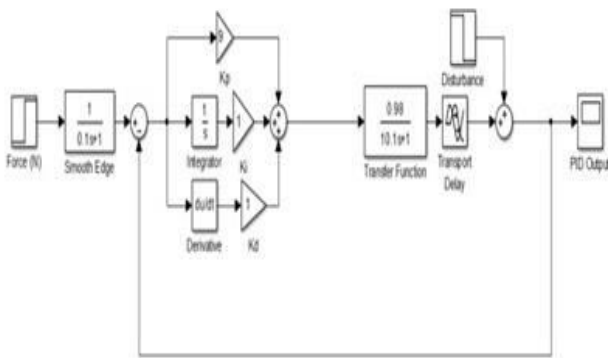


Figure-5. Simulink of ducted fan controlled by PID controller with disturbance.

Apart from the PI controller Simulink design, the PID controller is also being experimented (e.g. see Figure-5). Based on the simulation result in Figure-6, after the adhesion force reduce almost 7N, it costs 2.3 s for the wall climbing robot to return to the steady-state and the adhesion force active accelerate to 51 N again.



Figure-6. Graph of adhesion force (N) against time (s) of PI and PID using Nichols-Ziegler tuning method.

Table-5. Comparison of PI and PID using manual and Ziegler-Nichols tuning method.

Tuning Method	Controller	Kp	Ki	Kd	Maximum Overshoot, Mp (%)	Settling Time, Ts (s)	Rise Time, Tr (s)	Disturbance, d(t) (s)
Manual Tuning Method	PI	9	1	-	11.74	15.0	2.08	4.0
	PID	9	1	1	1.96	4.2	2.15	2.3
Ziegler-Nichols Tuning Method	PI	11.025	5.0885	-	60	9.0	1.60	4.5
	PID	15.24	11.7231	4.953	62	7.5	1.10	3.0

As the additional analysis in this experiment, the effect of tuning PI and PID using manual technique and Ziegler-Nichols tuning method is also being analyzed. The results is shown in Table-4. Based on the table, it is proven that the PID controller is the more suitable controller for the wall climbing robot system for both tuning method as compared to the PI controller. PID controller using manual tuning has the lowest maximum overshoot percentages compared to PI controller. The PID settling time is relatively faster than PI. Even though the rise time of PID is a bit slower than PI controller in manual tuning method, but it still can be consider fast because it does not exceed 3sec. The PID controller also has the faster response when there is gap interference occur.

As the conclusion, PID controller using manual tuning method is more preferred to be use in this system as.

CONCLUSIONS

This project describes a pressure control of wall climbing robot using PID controller. The developed wall climbing robot is basically divided into 3 parts, in order to adapt the unpredictable working environment. An adhesion adaptive control method using PID is adopted, which enhanced the efficiency of the robot when working on wall surfaces with various roughness.

The feasibility of adhesion adaptive control method based on PID is demonstrated by simulation results and the system gets a well dynamic response quality to satisfy practical application. Compared to conventional PI control method, PID control method has less energy consumption and more endurance capacity. It makes robot perform more reliable when facing chamber leakage situations.

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