# Modeling and Analysis of a Dust Cleaning Robot

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***Abstract***

*Dust in offices and homes tend to create respiratory problems for infants as well as adults. Removal of dust is of significant importance in a lot of applications like solar panels whose efficiency reduces almost by 10-40% due to soiling. Cleaning is achieved by the shear force generated due to the velocity gradient which overcomes the adhesion of dust to the surface. The present work shows a mathematical model of a dust cleaning robot in a horizontal configuration. The robot consists of a 3M cleaning pad material attached to a motor which will clean the surface after suitable spraying of the cleaning liquid at regular intervals. As dust gets collected the inertia and frictional torque changes which affect the performance and this is incorporated in the model. The model parameters will be identified by suitable experiments conducted at Mechatronics Lab, RCOE.*

***Keywords:*** *dust cleaning, mathematical model, friction, torque, robot*

## 1. Introduction

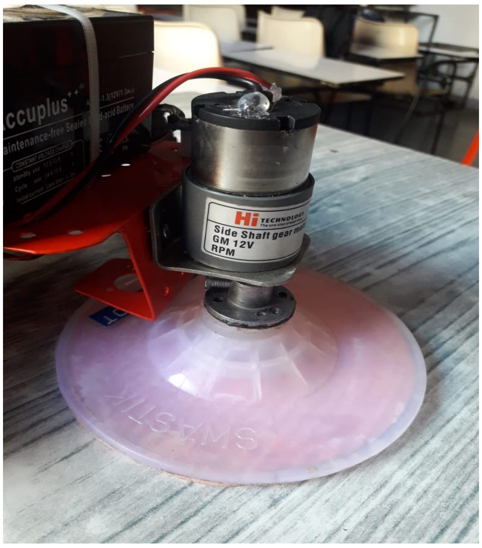
In today's scenario, with the ever increasing vehicle population, pollution levels are increasing which causes the air to be denser and allows dust to settle quickly within the vicinity. The same dust may get blown into the air and cause respiratory problems for people in-case they inhale them. Also, places like hospitals need to have extremely clean environments for patients and lot of time is consumed in the same leading to less time for patient care. Clean rooms used for manufacturing of aircraft components also need to be upto a standard and hence dust removal is of utmost importance in such scenarios.

## 2. Working

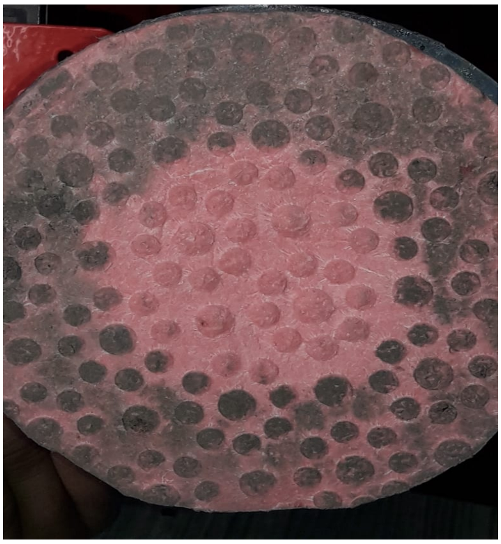
This paper introduces a low cost and compact design for a floor cleaning robot which will clean the horizontal surfaces of buildings [1]. The design incorporates the use of motor attached to cleaning pads which will efficiently clean the floor. Also, a drip mechanism is used to spray the homemade cleaning liquid which works in synchronism with the motors and cleaning pads and sprays at regular intervals. As dust gets collected the inertia and frictional torque changes which affect the performance of the robot and is incorporated in a mathematical model. The model parameters are determined in Section 3 which would result in optimal cleaning of the floor surface. The robot would be able to replace human effort.

## 3. Mathematical model of the Robot

The robot consists of a 3M cleaning pad which weighs around 5 gms attached to a motor as shown in Figure 1. The velocity of rotation generates a shearing action which actually overcomes the adhesion force of the dust particles and accordingly removes the dust from the surface. The frictional torque is derived in section 3.1 and the mass of dust collected by the pad is modeled in Section 3.2.




(a)



(b)

**Figure 1 : (a) Cleaning pad attached to motor (b) Pad effectiveness after cleaning**

### 3.1. Calculation of frictional torque

Frictional force provided by a ring of radius r and thickness dr is given by

$$F_r = \mu (m_o + M + m) g (2\pi r dr)/\pi R^2 \quad \text{.................................. (1)}$$

In this case, the amount of dust gathered is considered to add to the frictional torque.

Upon integrating (1) from limits of r = 0 to r = R, total frictional torque,

$$T_r = \int F_r x r = 2\mu (m_o + M + m) gR/3 \quad \text{................................(2)}$$

### 3.2. Derivation of transfer function model for cleaning pad

The transfer function for a cleaning pad derives the relationship between velocity and torque based on the following formulation

Input torque = Inertial torque + Frictional torque

$$Inertial\ torque = d(I\omega)/dt = [(m_0 + m) R^2/2] d\omega/dt + (\omega R^2/2) dm/dt \quad \text{..........(3)}$$

where m = mass of dust collected by pad

$$Frictional\ torque = 2\mu (m_o + M + m) gR/3 \quad \text{...................(4)}$$

Let us model the amount of dust collected

m = bv ..............................(5)

where v is the velocity of the pad and b is the cleaning constant

Combining (3) and (4) and substituting from (5), we get

$$T = [(m_0 + bv) R/2] dv/dt + (Rv/2)(bdv/dt) + 2\mu (m_o + M + m) gR/3$$

$$T = (m_0 R/2) dv/dt + (bRv)(dv/dt) + 2\mu bgRv/3 + 2\mu (m_o + M) gR/3 \quad \text{............(6)}$$

Taking Laplace transform of each of the terms on both sides, we get

$$\int T\,e^{-st}\,dt = \int (m_0 R/2)\,dv/dt\,e^{-st}\,dt + \int (bRv)(dv/dt)\,e^{-st}\,dt$$
$$+\int [2\mu\,bgRv/3]\,e^{-st}\,dt + \int [2\mu(m_o+M)\,gR/3]\,e^{-st}\,dt \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The second term *(bRv)(dv/dt)* needs special attention to be converted into appropriate Laplace function as shown below

$$I = \int v(dv/dt)\,e^{-st}\,dt$$

Integrating by parts, we get

$$I = v\,e^{-st}\int (dv/dt)\,dt - \int [d/dt\,(v\,e^{-st})\int (dv/dt)\,dt]\,dt$$

$$I = v^2 e^{-st} - \int [dv/dt\,e^{-st} + v\,e^{-st}(-s)]\,v\,dt$$
$$I = v^2 e^{-st} - \int v\,dv/dt\,e^{-st}\,dt + \int sv^2 e^{-st}\,dt$$
$$2\mathrm{I} = v^2 e^{-st} + \int sv^2 e^{-st}\,dt = v^2 e^{-st} + s[v^2\int e^{-st}\,dt - \int 2\mathrm{v}\int e^{-st}\,dt\,dt]$$
$$2\mathrm{I} = v^2 e^{-st} + s[(-v^2/s)\,e^{-st}] - 2\mathrm{s}\int v\,e^{-st}/-s\,dt$$
$$2\mathrm{I} = 2\int v\,e^{-st}\,dt$$

Hence,

$$I = V(s) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Making substitution of (8) in (7), we get

$$T(s) = (m_0 R/2)\,sV(s) + bRV(s) + 2\mu\,bgRV(s)/3 + 2\mu(m_o+M)\,gR/3\mathrm{s}$$

Grouping the terms together and taking $T(s) = T_0/s$ , we get the transfer function as below

$$T_0/s = V(s)[(m_0 R/2)s + 2\mu\,bgR/3 + bR] + 2\mu(m_o+M)\,gR/3\mathrm{s}$$

Rearranging to put in time constant form, we get

$$\boxed{V(s)/T(s) = [(3T_0 - 2\mu(m_0 + M)gR)/(2\mu bgR + 3bR)]/[3m_0/(4\mu bg + 6b)]s + 1)}$$

where

$$K = (3T_0 - 2\mu(m_0 + M)gR)/(2\mu g + 3)bR \text{ and } \tau = 3m_0/(2\mu g + 3)2b$$

## 4. Simulation Results and Discussion

The model is simulated in MATLAB 2014a with the parameters shown in Table 1 below. The response of the model is exponential in nature and will reach 95% of the maximum value at a time of $3\tau$. The value of $\tau$ needs to be determined experimentally. Extensive research will be carried out in Mechatronics Lab, RCOE for this purpose.

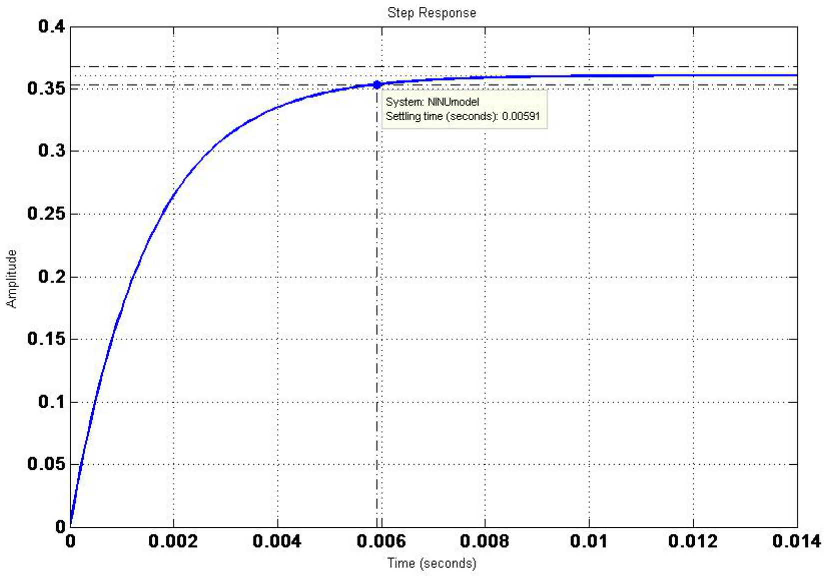



**Figure 2 : Simulation result of dust collection for cleaning pad**

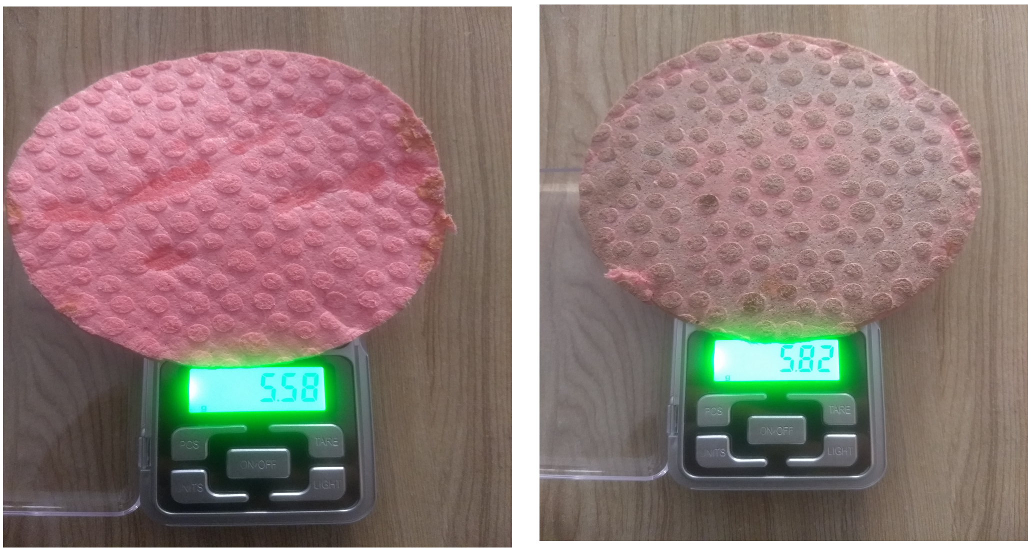
## 5. MATLAB Code

```
>> To = 0.036;
>> R = 0.06;
>> mo = 0.005;
>> mu = 0.1;
>> g = 9.81;
>> M = 0.125;
>> b = 1; % taken for simulation purpose
>> K = (3*To - 2*mu*mo*g*R)/((2*mu*g + 3)*b*R)
K = 0.3608

>> tau = 3*mo/((2*mu*g + 3)*2*b)
tau = 0.0015

>> s = tf('s');
>> num = K;
>> den = [tau 1];
>> NINUmodel = tf(num,den);
>> step(NINUmodel)
```

**Table 1 : Parameters used in simulation**

| Parameters | Description | Value | Units |
|---|---|---|---|
| $T_0$ | Torque of motor | 0.036 | N-m |
| $m_0$ | Mass of clean pad | 0.005 | kg |
| **M** | Mass of motor | 0.125 | kg |
| **b** | Cleaning constant | Unknown and to be determined experimentally and dependant on ω | kg-s/m |
| **R** | Radius of cleaning pad | 0.06 | m |
| **µ** | Coefficient of friction | 0.1 | NA |

The results of cleaning process can be seen in Figure 3 below. The experiment indicates that there is a increase in weight of pad post dust collection and hence will affect the inertial as well as frictional torque of the motor. This same effect is captured by increase of current drawn by the motor and hence the cleaning constant will be calibrated accordingly. The cleaning constant will depend on the surface of the material that is being cleaned.




**(a) (b)**

**Figure 3 : (a) Mass of clean pad (b) Mass of pad after gathering dust**

## Conclusions and Future work

Based on the mathematical model, we can also say that the trials will be conducted to arrive at a proper desired velocity of cleaning. We have found through simulation that cleaning efficiency increases with increase in velocity. The robot will be moved on the floor in horizontal configuration specifically for this purpose. Instead of water, we will be using a homemade cleansing solution which will more effectively clean the surface of the floor. Suitable electronic circuits will be designed so that the final robot will be able to carry out the tasks successfully. Furthermore, appropriate industry standard controllers will be designed to optimize performance and algorithms related to obstacle avoidance will be incorporated in the future work.

## Acknowledgments

We would like to thank Hi Technologies for providing us with the motors required for the experiment. Also, we would like to thank K-Strok for providing us with the best quality 3M cleaning pads. At last we must express my sincere heartfelt gratitude to all the staff members of Mechanical Engineering Department who helped us directly or indirectly during this course of work. Our sincere thanks to our Head of the Department, Dr. Sujata Rout and Principal, Dr. Varsha Shah for motivating us in doing the project.

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