

# Design of Electrostatic Adhesion Pads for Wall Climbing Robots

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## ABSTRACT

*In this paper, work has been carried out to design adhesion pads vertical climbing robot with a unique type of surface adhering technology. This technology has wide application prospects for wall climbing robots because of its unique characteristics compared with other types of adhesion technologies. With this technology the robot prototype can climb many vertical surfaces such as glass, wood, drywall, plastic etc. This adhering technology is called the electrostatic adhesion. The principle of electrostatic adhesion with its characteristics and advantages is described in detail. For the purpose of this work an electrostatic adhesive pad was designed and fabricated to gauge the possibility of the electrostatic adhesion technology to be applied on the vertical climbing robots. Experimental tests were carried out to analyze the adhesion and mobility performances of the robot prototype. The performance of the straight line movement of the robot was evaluated on the different surfaces. The experimental results of this study will provide a strong base for the favorable design of vertical climbing robots for various applications based on electrostatic adhesion mechanism in the future.*

**Keywords:** Electrostatic Adhesion, Wall climbing Robot, Electrostatic forces, Electrostatic adhesion pads, vertical climbing robot

## 1. INTRODUCTION

Today's climbing and walking robots are a combination of manipulative, perceptive, communicative, and cognitive abilities and they are capable of performing many tasks in industrial and nonindustrial environments. Surveillance, planetary exploration, emergence rescue operations, reconnaissance, petrochemical applications, construction, entertainment, personal services, intervention in severe environments, transportation, medical and etc. are some applications from a very diverse application fields of climbing and walking robots. The utility and scope of these robots, however, are fundamentally limited by their abilities to navigate unstructured environments. By great progress in this area of robotics it is anticipated that next generation climbing and walking robots will enhance lives and will change the way the human works, thinks and makes decisions.

One of the most challenging tasks in a climbing robot design is to develop a proper adhesion mechanism to ensure that the robot sticks to wall surfaces reliably without sacrificing mobility [1]. The method of adhesion has become a bottleneck of development and application of wall climbing robots, so there has been a sustained interest in pursuing novel adhesion methods, which can benefit from simplicity, light-weight and work stability of the robots. So far, four types of adhesion techniques have been investigated:

- 1)Magnetic devices for climbing ferro magnetic surfaces
- 2)Vacuum suction techniques for smooth and nonporous surfaces
- 3)Attraction force generators based on aerodynamic principles
- 4)Biomimetic approaches inspired by climbing animals. [2]

This paper describes a novel and existing method of adhesion which can be applied to vertical climbing robots satisfactorily. This method of adhesion is the electrostatic adhesion. Electrostatic adhesion is based on the use of compliant surfaces with patterns of compliant electrodes designed to create electrostatic forces of attraction between an object (the robot) and a substrate (building surface). Electrostatic adhesion is a technique available for developing adhesion forces, which is similar to popular methods, such as vacuum suction and magnetic adhesion. Electrostatic force is employed in various applications, such as fabric handling, electrostatic chuck (ESC) handling of silicon wafers, handling rough objects, levitation and transportation of silicon wafers and electrostatic glass actuators.

## 2. ELECTROSTATIC ADHESION

Electrostatic adhesion is an electrically controllable adhesion technology that involves inducing electrostatic charges on a wall surface using a high voltage power supply connected to a specific electrode panel. Electrostatic adhesion is based

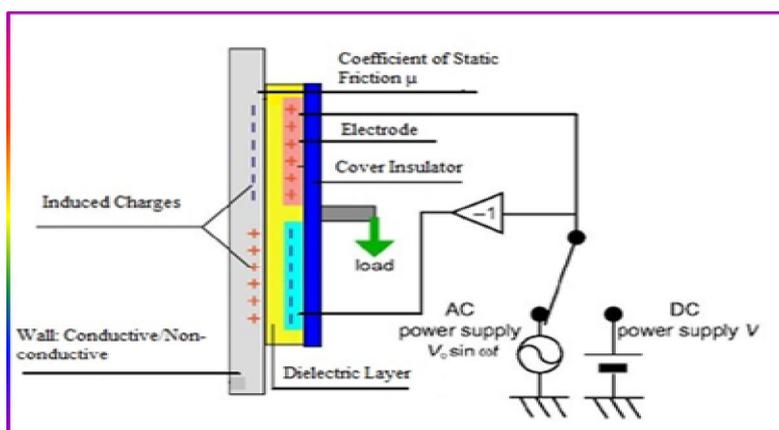
on the use of flexible compliant surfaces with patterns of compliant electrodes designed to create electrostatic forces of attraction between an object (the robot) and a substrate (wall surface).[3]

The electrode panel is typically comprised of at least two sets of independent conductive electrodes at different potentials that are deposited on the surface of a polymer. When alternate positive and negative charges are induced on adjacent electrodes on the application of high voltage, the electric fields set up opposite charges on the wall surface and thus cause electrostatic adhesion force between the electrode panel and the wall surface. These charges do not neutralize themselves to those on the clamp because of the trapped air gaps as well as insulator material on the clamp Fig 1, Fig2. The physical mechanisms of the electrostatic adhesion against conductive wall and dielectric wall are slightly different since the induced charges on the conductive wall are free charges generated by electrostatic induction while that on dielectric wall are polarization charges generated by dielectric polarization. The electrostatic adhesive force generated between the electrostatic adhesive pad and the wall surface can be calculated using a simple text-book equation.[4]

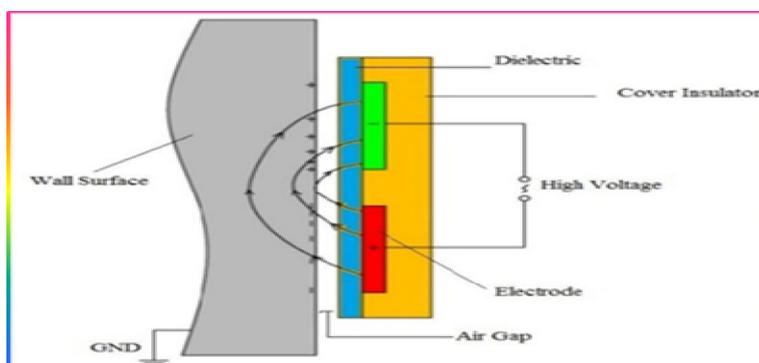
$$F_e = \frac{1}{2} \epsilon A \left( \frac{V_0}{d} \right)^2 \sin^2 \omega t$$

Where  $\epsilon$  is the dielectric constant of the dielectric layer,  $A$  is the area of electrodes,  $V_0$  is the applied voltage, and  $d$  is the gap between electrodes and the substrate surface. If DC voltage is applied to the electrodes then the electro adhesive force can be calculated as:

$$F_e = \frac{1}{2} \epsilon A \left( \frac{V_0}{d} \right)^2$$



**Figure 1** principle of electrostatic adhesion



**Figure 2** Charge Transfer during Electrostatic Adhesion

### 3. MATERIALS FOR THE DEVELOPMENT OF ELECTROSTATIC ADHESIVE PAD

There is a wide choice of materials for the components of the electrostatic adhesion pad. Generally, any electrically conductive material is a ready choice for the electrodes but the standard of choosing conductive electrodes is high compliance and excellent performance about inducing charges High compliance is important to insulate material too. The insulate material should have an excellent ability of insulation as the electrostatic adhesive pads should bear a high

voltage (typically 1--5 kilovolts) supplied by a power supply. Mylar and silicone rubber are more popular for the use as dielectrics. Dielectric materials with a higher dielectric constant are given more preference for strength and fabrication issues.

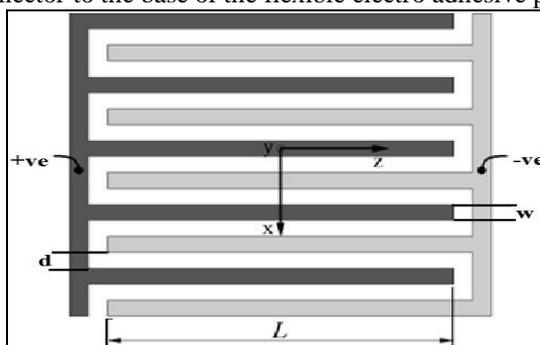
**Table 1** Observations of Electro adhesive Pads made with different material combinations

Panel No.	Electrode Material	Type of Electrode	Dielectric / Cover Insulator	V (kV)	Remarks
1	Cu	Inter-digital	Brown tape	~2	Adhesion observed but not satisfactory
2	Cu	Inter-digital	Mylar	~2	Nice adhesion Holds a weight of 75gms
3	Cu	Inter-digital	Lamination Sheet Material	~2	No result
	Cu	Plain	Mylar	~2	Low adhesive force observed
5	Al foil	Plain	Mylar	~2	Little Adhesion
6	Al foil	Plain	PVC Tape / Silicone Sealant (Acetic cure)	~2	Good Adhesion. Holds weight of ~80gms
7	Al foil	Inter-digital	PVC Tape / Silicone Sealant (Acetic cure)	~2	Very good Adhesion. Holds weight of ~100gms
8	Al sheet (2mm Thick)	Inter-digital	PVC Tape / Silicone Sealant (Acetic cure)	~2	No adhesion
9	PCB (0.8mm)	Inter-digital	Solder masked	~2	High Sparking
10	PCB (0.8mm & 0.2mm)	Inter-digital	Silicone Sealant (Acetic cure)	~2	No adhesion
11	Al foil	Inter-digital	PVC Tape / Silicone Sheet used as Keyboard Protector	~2	Very Good Adhesion. Holds weight of ~200gms

After a lot of work and testing of various electrostatic adhesive pads with different combinations of materials, the pads with thick heavy duty Aluminum foil shaped in form of rectangular inter-digital electrodes fixed over a PVC tape, which acts as a cover insulator and also holds the electrodes and dielectric in place gave the best results for electrostatic adhesion. With this combination, commercially available keyboard protector film was used as the dielectric.

**4. ELECTROSTATIC ADHESIVE PADS**

The electrostatic adhesion pad was fabricated in the lab by cutting the Aluminum foil using a plastic stencil & blade to the required shape and size of dimension 120\*160 mm. The electrode structure consists of two interpenetrating comb electrodes, each having a number of fingers of length  $L = 100\text{mm}$ . The width of the electrodes  $w = 3\text{mm}$  and the space between the neighboring electrodes is  $d = 2\text{mm}$ . The base of the pad or cover insulator is a PVC tape with thickness  $d_1 = \sim 42\mu\text{m}$  and the keyboard protector film or dielectric with thickness  $d_2 = 200\mu\text{m}$  covers the electrodes on the top of the panel which is the side that comes in contact with the wall surface. A square frame made of 2mm thickness acrylic was then attached as a mechanical connector to the base of the flexible electro adhesive pad (Fig3, Fig4).



**Figure 3** Shape and Structure of the Electrodes – Inter-digital Form



**Figure 4** Flexible electro adhesive pad developed using Aluminum electrodes

These pads were tested at different surfaces with an input voltage of 2.5kV (DC) and following results were obtained, Table 2, (Fig 5).

**Table 2** Design Specifications for the Electrostatic Adhesion Pad

Component of Pad	Material / Specification
Area	120 mm*160 mm
Electrode	Aluminum foil, ~ 24 $\mu$ m
Dielectric	Keyboard protector (silicone rubber), 200 $\mu$ m
Cover insulator	PVC tape, ~ 42 $\mu$ m
Electrode Width (w)	3mm
Electrode Gap (d)	2mm
Voltage Applied	~2500 V



**Figure 5** Application of weights on the different Electro adhesive pads on glass surface

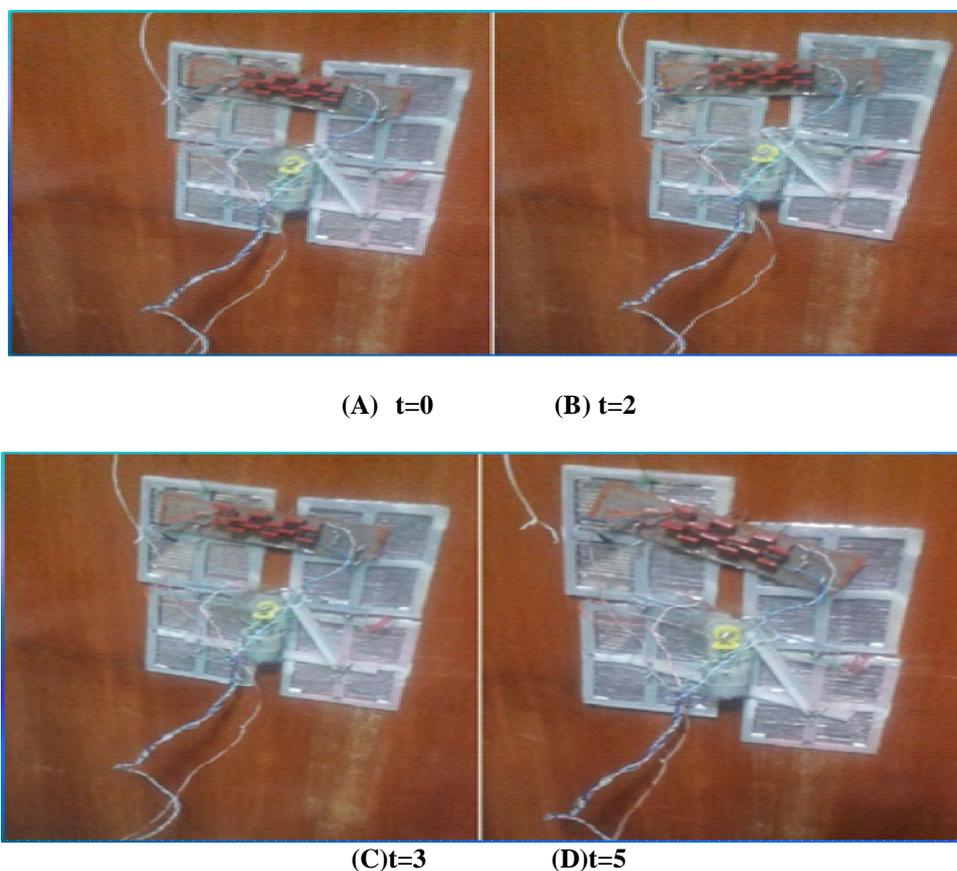
**Table 3:** Holding Weight of Adhesive Pads for Different Materials

Surface Material	Voltage(AC – DC)	Holding Weight
Glass	2500 V	250 grams
Wood	2500 V	220 grams
Dry Wall	2500 V	~200 grams

From Table 3, it can be seen that the electrostatic adhesion force can hold up a reasonable sized robot on all of the three kinds of surfaces at the same voltage. However, there are some other practical problems that need to be considered when the electrostatic adhesion mechanism is applied to wall climbing robot, such as the resisting of peeling moment and dynamic properties of the robot.

**5. PERFORMANCE OF PADS**

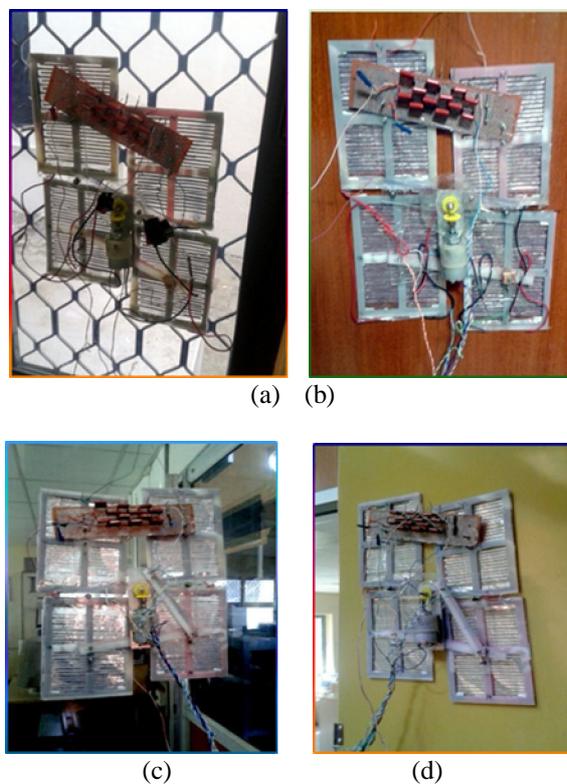
One robot prototype has been developed using 4 such kind of electrostatic adhesive pads. The adhesion and mobility performances of the robot prototype were tested and examine on various types wall surfaces. The performance of the straight line movement of the robot was evaluated on different surfaces. The robot could achieve forward and backward movements along a straight line on different wall surfaces by controlling the synchronous motion of the two legs or pads through the geared DC motor. When the robot moved on the wall surface, the contact area between the electrostatic adhesive pads and the wall surface was changing all the time. The electrostatic adhesion force generated by the electrode panel when the robot was moving on the wall surface was smaller than when the robot was placed on the wall statically, due to the time delay in the excitation and adhesion force generation (Fig 6). Resisting the peeling effect and reducing the weight of the robot to minimize the sliding were the major concerns for developing the robot prototype. In this work, lightweight materials and components were used in the fabrication to reduce the self-weight as much as possible. The robot components such as the motor and electronics were placed in the robot structure such that they were close to the wall surface thereby making the robot body to be as flat as possible against the wall and also minimize peeling moment. It was verified that the robot proposed in this report can work satisfactorily on different kinds of wall surfaces (Fig 7).The performance parameters of robots are shown in table 4.



**Figure 6.** Snapshots of robot moving on wooden surface at different time intervals

**Table 4 :** Performance Parameters of the Robot Prototype

Size	330mm*265mm*45mm
Self-Weight	400 grams
Pay load	1 kg
Power Supply to Control System	12 V
Power Supply to Electrostatic Adhesive Pads	2500 V
Maximum Speed	5 cm/sec
Holding Weight of Each Pad	~ 250 grams



**Figure 7:** Robot clinging on different wall surfaces (a) Window pane made of Glass (b) Wooden Wall (c) Glass Wall (d) Acrylic / Plastic door

## 6. CONCLUSION AND FUTURE SCOPE

Electrostatic adhesion is an upcoming innovative technology for vertical climbing robots. It has the advantages of adhering to various types of material surface, light weight, fast clamping and unclamping over other conventional technologies. The principle of electrostatic adhesion was studied and an electrostatic adhesive pad was designed & fabricated in the lab. The adhesion performance of the electrostatic adhesive pad was analyzed to gauge the workability of the electrostatic adhesion technology on the vertical climbing robot. The results verify the possibility of the application of the electrostatic adhesion mechanism on the wall climbing robots.

It was observed that to implement the robot for use in practical applications more research is required to improve and refine the robot mechanism. Further study is required to design a dynamic adhesion force model during the locomotion of the robot with the electrostatic adhesive pads. Another area of investigation for the future would be to focus on the adaptive control of the vertical climbing robot based on electrostatic adhesion mechanism by automating the robot with feedback and control, which can help the robot recover from accidental slippage.

With required modifications this system can be used for various inspection processes like generator inspection, condenser inspection etc.

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