Microrobotics

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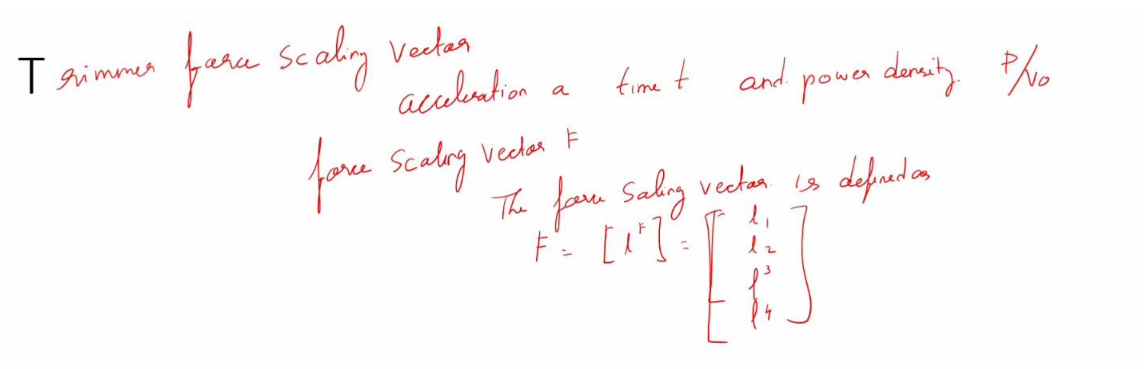
Week- 01

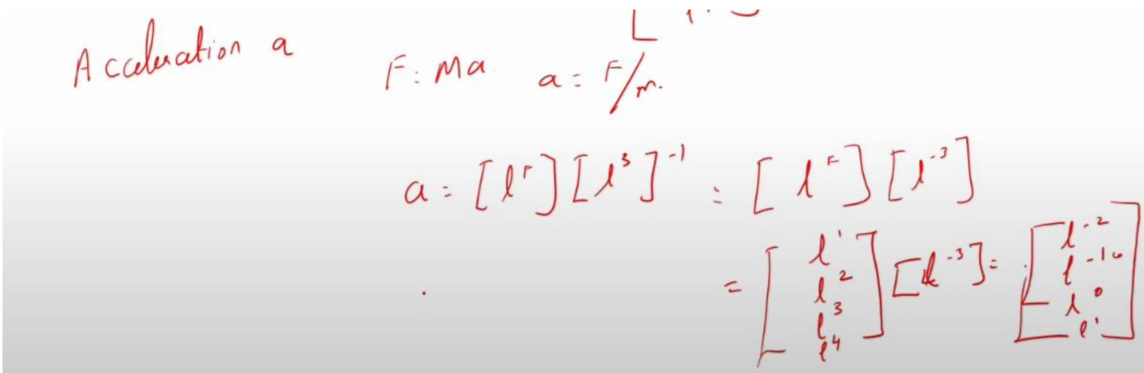
Lecture No- 03

Scaling Laws of Microrobots - Module 01

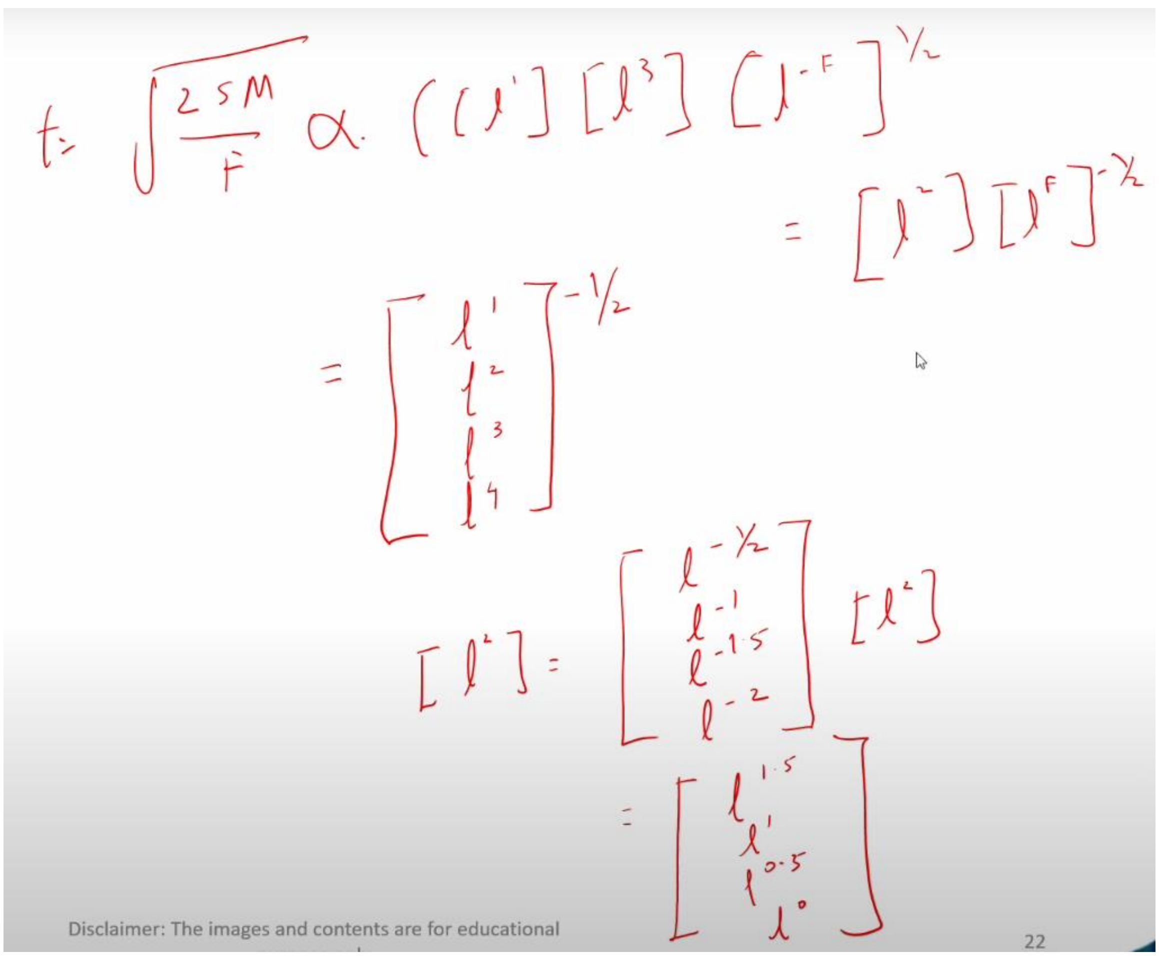
we have been discussing these scaling laws of micro robots. In fact, we had discussed this rigid body dynamics with reference to the scaling laws of rigid body dynamics. Until now, we have discussed scaling and dynamic forces. Now we are going to discuss these trimmer forces for scaling vectors. So, the trimmer force is a proposed unique matrix to represent force scaling-related parameters for acceleration that are represented as time T and power density P by V0, which is required for the scaling of the system in rotation. So, this matrix has a generic name, i. e., force scaling vector F. The force scaling vector is defined as F equals LF, which is L1, L2, L3, and L4. Further derivation of other quantities based on the above vector shall follow.



One of the quantities we can focus on is acceleration, which we can term as "a." So, f equals ma. Where a equals f by m. The following scaling can be obtained as a equals Lf by L^3 minus 1, which is nothing but Lf by L to the power of minus 3, which can be written as L^1, L^2, L^3, and L^4, L to the power of minus 3, which can be represented as L minus 2, L minus 1, L 0, and L 1. Further, the transient time and the subject formula relation can be represented as T equals the square root of 2sm by f L1, L3 minus f 1 by 2, which can be written as L squared Lf to the power of minus 1 by 2.

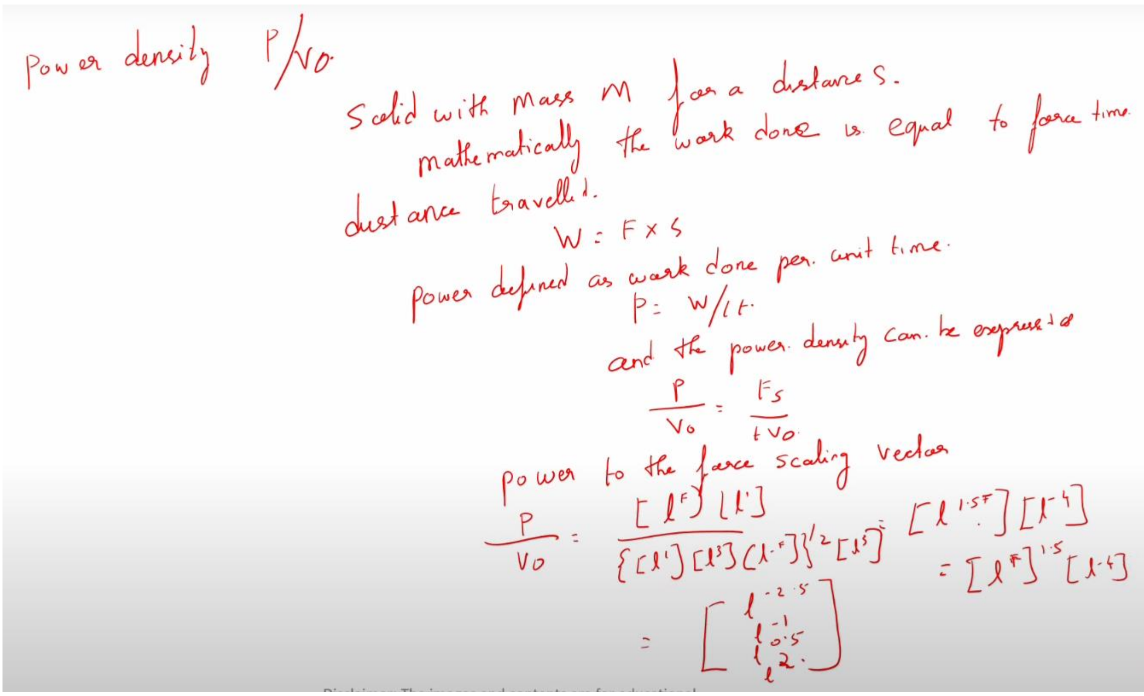


This can be further elaborated as L1, L2, L3, and L4 minus 1 by 2. So, l power 2 can be written as l power minus 1 by 2, l power minus 1, l power minus 1.5, l power minus 2 whole power 2 which can be written as l power 1.5, l power 1, l power 0.5 and similarly, if we try to consider the power density, the power density can be represented as P by V naught.



So power is a very important parameter in the design of micro robots, and insufficient power supply to these micro robots can result in inactivity of the system. On the other hand, the system may suffer structural damage such as overheating and excessive power supply.

Excessive power requirements by a micro robot will increase the operational cost and reduce the operational life of such devices when incorporated in field-related applications. So, here we deal with the power density. When we try to derive the power supply with work, it is required to move the solid with mass m for a distance S.



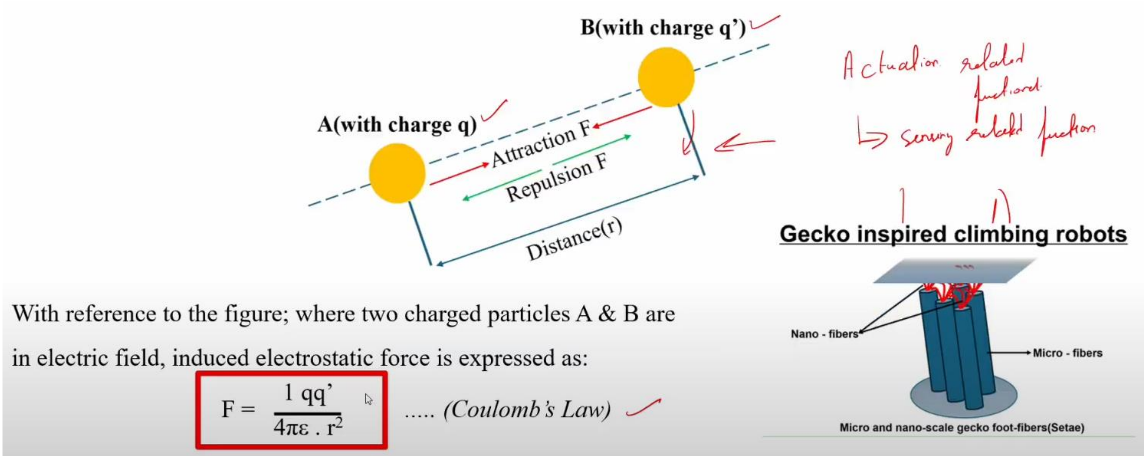
Mathematically, the work done is equal to force times the distance traveled. So, that is w equals f times s; thus, the power is defined as the work done per unit time. which is represented as P = W / T and the power density can be expressed as P / V0, which equals Fs T / V0. So, when we try to relate this power density to the force scaling vector, it can be represented by L1, L3, L minus f, 1 by 2, L3, which can be further represented as f L minus 4, Lf 1.5 L minus 4. So, the final power density with reference to force scaling can be represented as L minus 2.5, L minus 1, L 0.5, and L 2. So this is the relation that talks about the power with reference to four scaled vectors. Further discussion on the contribution of electrostatic force, how these electrostatic forces and electromagnetic forces are contributing to these robotic systems.

So let us discuss the scaling that is involved in an electrostatic force. So when we look into the electrostatic charges, it induces an electrostatic force, which is expressed by Coulomb's law, where A has charge q. With charge q, the attraction force F and the repulsion force F exist at a distance r between the two charges that exhibit both attraction and repulsion. So, it is governed by Coulomb's law that is (1*q q')/4 pi omega by epsilon r^2. As far as these electrostatic charges are concerned, if we look into the different types of biomimicking robots, most of these robots require a certain kind of actuation for appropriate functionality, either for climbing or to adhere to the surface; in the case of targeted drug delivery, it should attach to the surface.

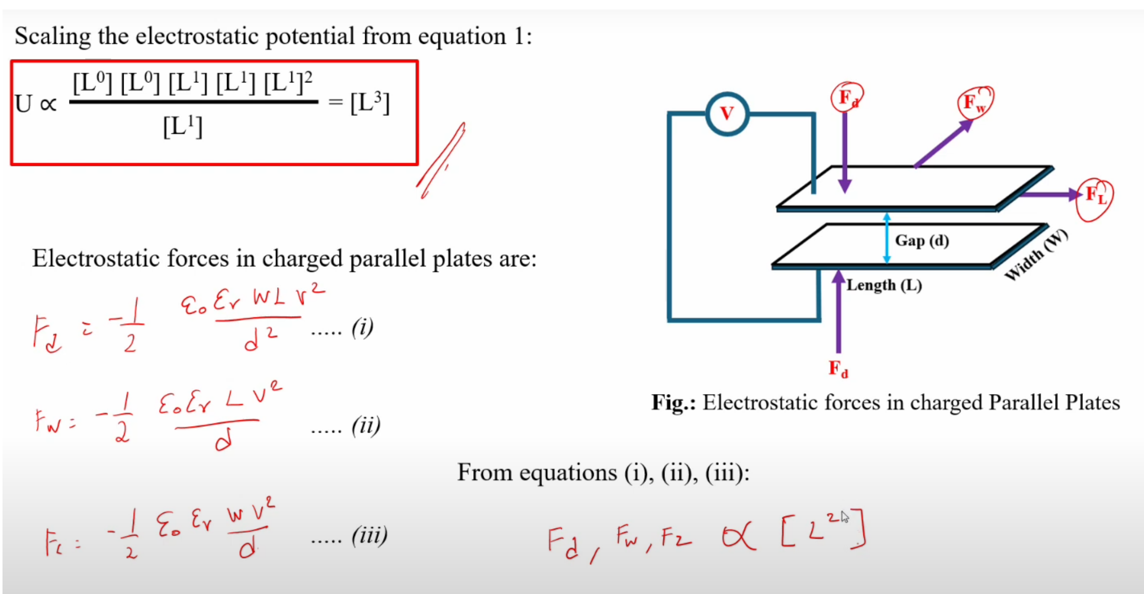
For those conditions, we deploy different forces that are generated. So, one of the forces that are prominently used for such kinds of micro robotic applications is this electrostatic force. As far as applications are concerned, these electrostatic actuators are used for micromotors and robotic arms. As far as the microfluidic perspective, these electrostatic forces control fluid movement in lab-on-chip devices. Now one of the key applications that is highly focused on with reference to this electrostatic perspective is adhesion and locomotion. Adhesion of a small micro robot to a wall or surface caters to different functionalities, including surveillance, inspection, or sometimes it is also used for targeted drug delivery and locomotion. Discussing locomotion, the concept of resolution of locomotion automatically comes into the picture. So, the actuation mechanism should have an appropriate capability to control the locomotion. From that perspective, electrostatic force helps micro robots grip and move on a surface with intermittent displacement. From a biomedical perspective, the microrobots enable cell transport and are also used for electrophoretic drug delivery as well as biosensing.

Now, when we look at the overall principle of this electrostatic actuation, as far as this electrostatic actuation is concerned, there is an external acceleration based on the pressure applied. The pressure will impact the material, and finally, an electrostatic pressure will be generated appropriately. Now, let us look into some of the mechanisms or some of the fundamentals that are involved with reference to these electrostatic generations and what the different parameters are that cater to this electrostatic system. Taking the case of the overall configuration of these electrostatic forces in a parallel plate, we have two parallel plates with a gap D and length L, and the voltage V to which it is connected. Let us take the electric potential of these two parallel plates into account.

So, with reference to the figure, the capacitance C is the charge plate, which is expressed as $C = \varepsilon r \varepsilon 0 A/D$, which can be rewritten as $\varepsilon r \varepsilon 0 W/LD$. So, the energy associated with this electrical potential can be represented as $u = -1/2\ Cv^2$. which can be rewritten as minus epsilon r epsilon naught wL V squared by 2D. Now, here ε_0 and ε_r correspond to the permittivity and relative permittivity of the dielectric medium between two electrodes, and V is the applied voltage across the system. When we investigate the scaling of this electrostatic potential, it is governed with reference to equation 1.



So this is a scaled electrostatic potential observed. When we observe different forces acting on these charged plates, we can denote these forces with reference to FL, Fw, and Fd. Fd is the force that caters to the gap, and Fw is the moment along the width W, while Fl is the moment along the width L. So, in that particular aspect, Fd equals minus 1 by 2 epsilon naught epsilon r WL v square by d square; Fw equals minus 1 by 2 epsilon 0 epsilon r L v square by D, and Fl can be represented as minus 1 by 2 epsilon naught epsilon r W v square by D. So, from the equation, we can say FD, FW, and FL are directly proportional to L squared.



So this is the overall configuration that is followed by these electrostatic forces. Now a question comes to our mind: why do we require this electrostatic actuation? As far as these electrostatic forces are concerned, they are ideal for actuating micro robots because they remain strong at small scales, and one of the important aspects with reference to these electrostatic systems is that they are well-versed and proven systems, and these systems can be easily manipulated at the micron level. By having these electrostatic motors, MEMS devices and electrostatic-based micro manipulators are some of the examples that basically discuss the application of these electrostatic charges for different systems. One of the key advantages of considering this electrostatic actuation is that gravity scales as k cubed, meaning it has the capability to overcome both gravity and inertia. In that aspect, we have the gravity scales, which can be represented as k cubed, that correspond to significant weakening at micro scales.

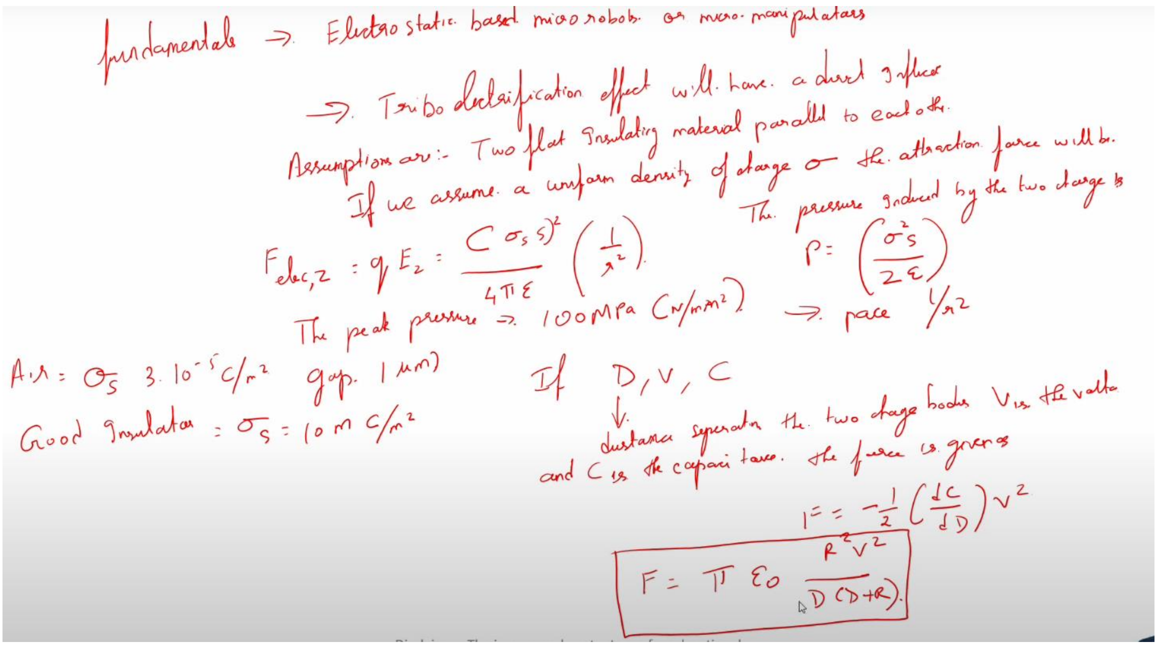
In addition, electrostatic forces scale better than gravitational and inertial forces, which makes them dominant in microsystems. As far as micro-manipulation and addition perspectives are concerned, these electrostatic forces enable precise object handling, especially as they have potential applications in cell manipulation, micro pick-and-place robots, etc. They are also used in electrostatic grippers for micro-assembly-related systems. Discussing the overall aspects or overall fundamentals and the associated parameters to consider while designing electrostatic-based micro robots or micro manipulators. We had discussed earlier that these electrostatic charges tend to accumulate on surfaces due to a variety of phenomena like triboelectrification and eventually migrate across insulating surfaces.

The mechanism of charging is complex and depends on the material considered as well as the environmental conditions. When we look into these environmental conditions, automatically this tribo-electrification effect will have a direct influence. Furthermore, this electro-charging will result in a non-equilibrium phenomenon that relaxes with time upon contact with the conducting surface. To analyze the characteristics of electrostatic force, we must first assume two flat insulating materials parallel to each other, and the objects may carry surface charges that will be attracted by the opposite charges on opposing forces. Ideally, our assumptions are two flat insulating materials parallel to each other.

So the uniform density of charge sigma, if we have uniform density of charge sigma, the attractive force will be F_elec_z, which can be represented as q_e_z, where sigma is s square by 4 pi by 1 by r square. Now considering the pressure induced by the two charge bases, P equals sigma square S 2 epsilon. So, this force rapidly decreases with the distance separation between the objects. The peak pressure can be in the order of 100 MPa, which decreases at a pace of 1 by r square. If we look at the typical order of magnitude of the charge density for air, it is in the range of sigma s 3 to 10 to the power of minus 5 per square meter, where the gap is close to around 1 micrometer.

In the case of a good insulator, sigma s is almost equivalent to 10 equivalent per meter squared. So for threshold charge density, the breakdown strength is reached and the insulator becomes conductive. For a native oxide like silicon, the breakdown strength is typically on the order of 30 megavolts per centimeter in air. The expression for the force can be generalized for any shape of perfectly conducting material. The electrostatic force is calculated from the electrostatic energy stored in the capacitor.

Let us consider dVc, where d corresponds to the distance separating the two charged objects, V is the voltage, and C is the capacitance; the force is given as F equals minus half dc by dV squared. The main issue involved is the determination of the capacitance. Some analytical solutions will help us for some particular geometries and ranges, for instance, for a sphere or a flat surface with an approximate force. It can be represented as F equals $\pi\varepsilon_0 r^2 v^2$ by d by d plus r. So, this is the overall force that is considered for an appropriate approximation.



Now, under these particular conditions, such as with reference to an electrostatic point of view, we have different forces that are being exhibited. Now, in extension of this electrostatic force, we have the electromagnetic force. So let us discuss the scaling effect in electromagnetic force and some of the different capillary forces that contribute to adhesion in detail in the upcoming lectures.