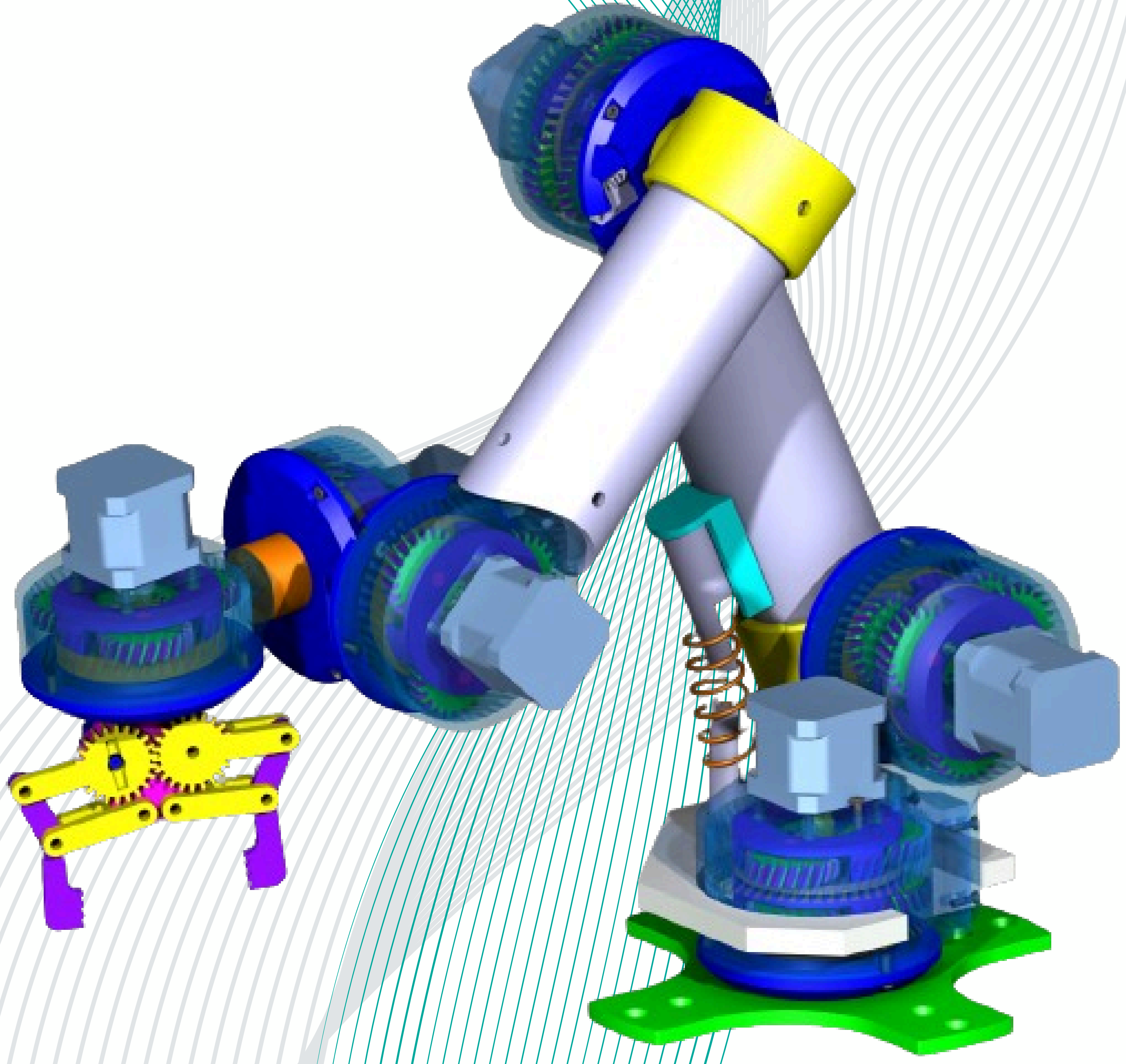
ROBOTIC ARM



E&M - PERIOD 3 GROUP 3

Contents

History

1950s: George Devol, an American inventor, developed the first programmable robotic arm in 1954

1961: Commercialized by Joseph Engelberger, the Unimate improved metalworking efficiency in the automotive industry. The Unimate was installed in a General Motors factory in New Jersey.

History (Cont.)

1970s - 1980s:

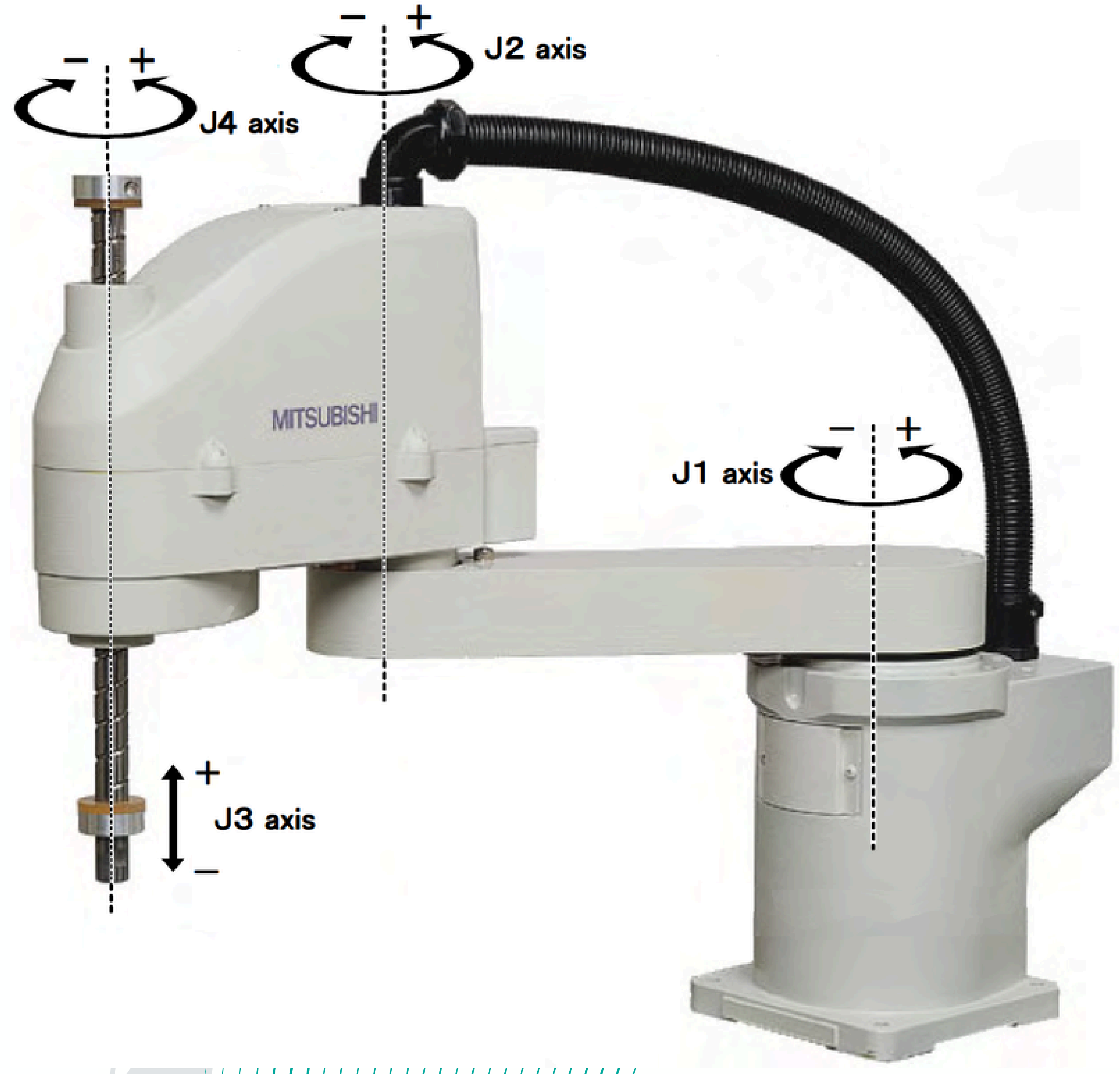
- Robotic arms widely used in automotive, electronics, & manufacturing industries
- European & Japanese companies (KUKA, ABB, & Fanuc) spearheaded innovation

1980s - 1990s:

- Control theory & software integration -> Flexible robots could execute precise and complex movements
- SCARA (Selective Compliance Assembly Robot Arm) -> Developed in 1981 -> Execute assembly line operations with speed and accuracy

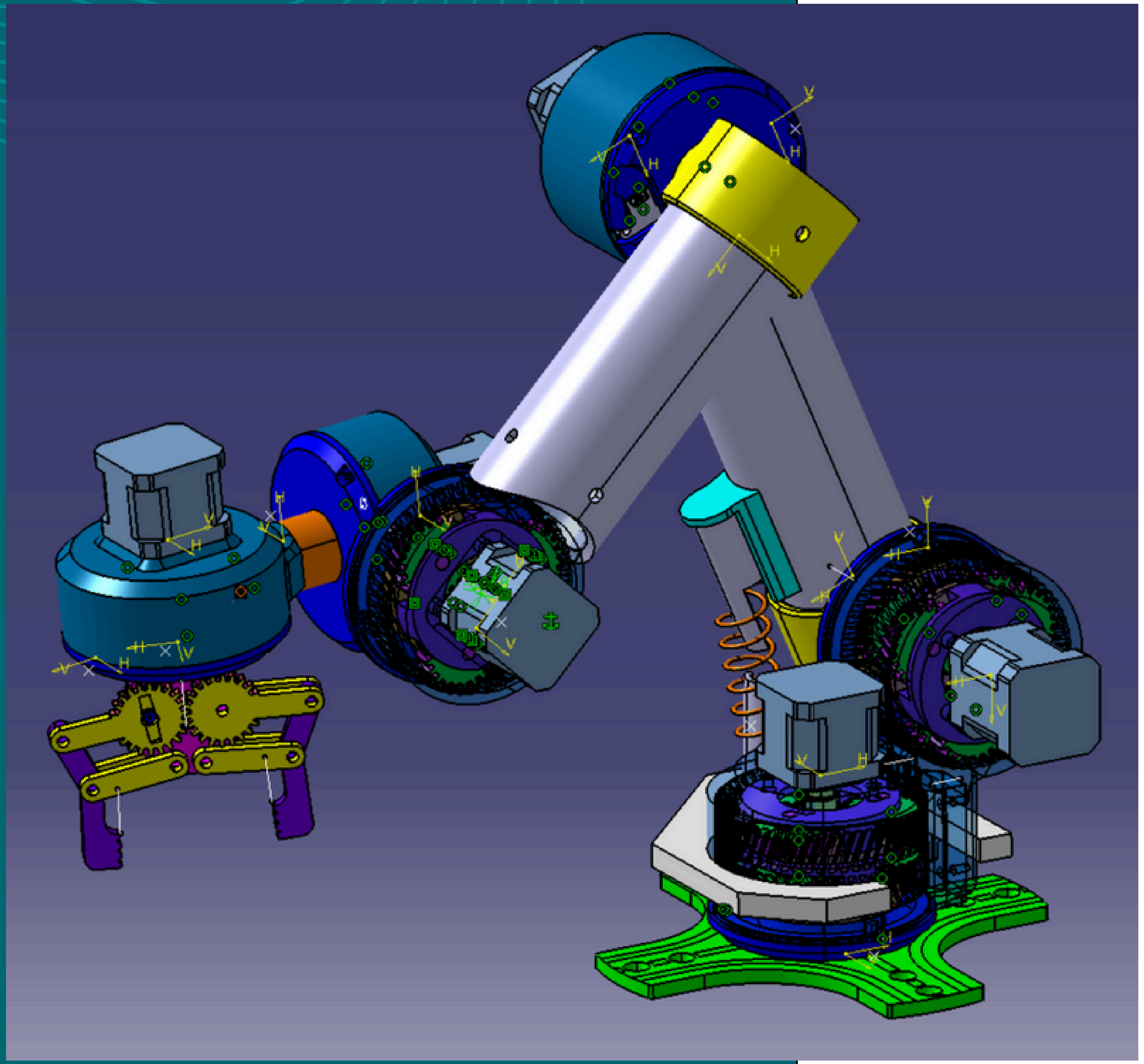
2000s - Present:

- Robotic arms are commonplace within manufacturing -> Flexibility and precision for repetitive tasks
- Increasingly used in surgery and defense



Product Overview

BRANDONW -- MAJOR COMPONENTS



STEPPER MOTORS

These are the 6 degrees of freedom of the robot arm. Each stepper has a full range of motion, although their position is limited by the wiring. These motors are controlled by sending them a target velocity to reach.

ELECTROMAGNET

The electromagnet can be toggled on and off. This can be used to pick up metal objects, such as paper clips or spoons.

GRIPPER

The gripper, similar to the electromagnet, can pick up objects. However, it is not reliant on the magnetic properties of the object it's picking up, and is able to pick up objects such as ping-pong balls or bar magnets. The controls allow for one to close and open the gripper to pick up and let go of objects, respectively.

GAMEPAD

There is a gamepad attached to the base of the robot that allows the user to control the motors using the 6 axes of the 3 joysticks, and the end-effector can be controlled by clicking the joysticks.

KEYBOARD

The keyboard has the same functionality as the gamepad but from the comfort of the host machine's keyboard.

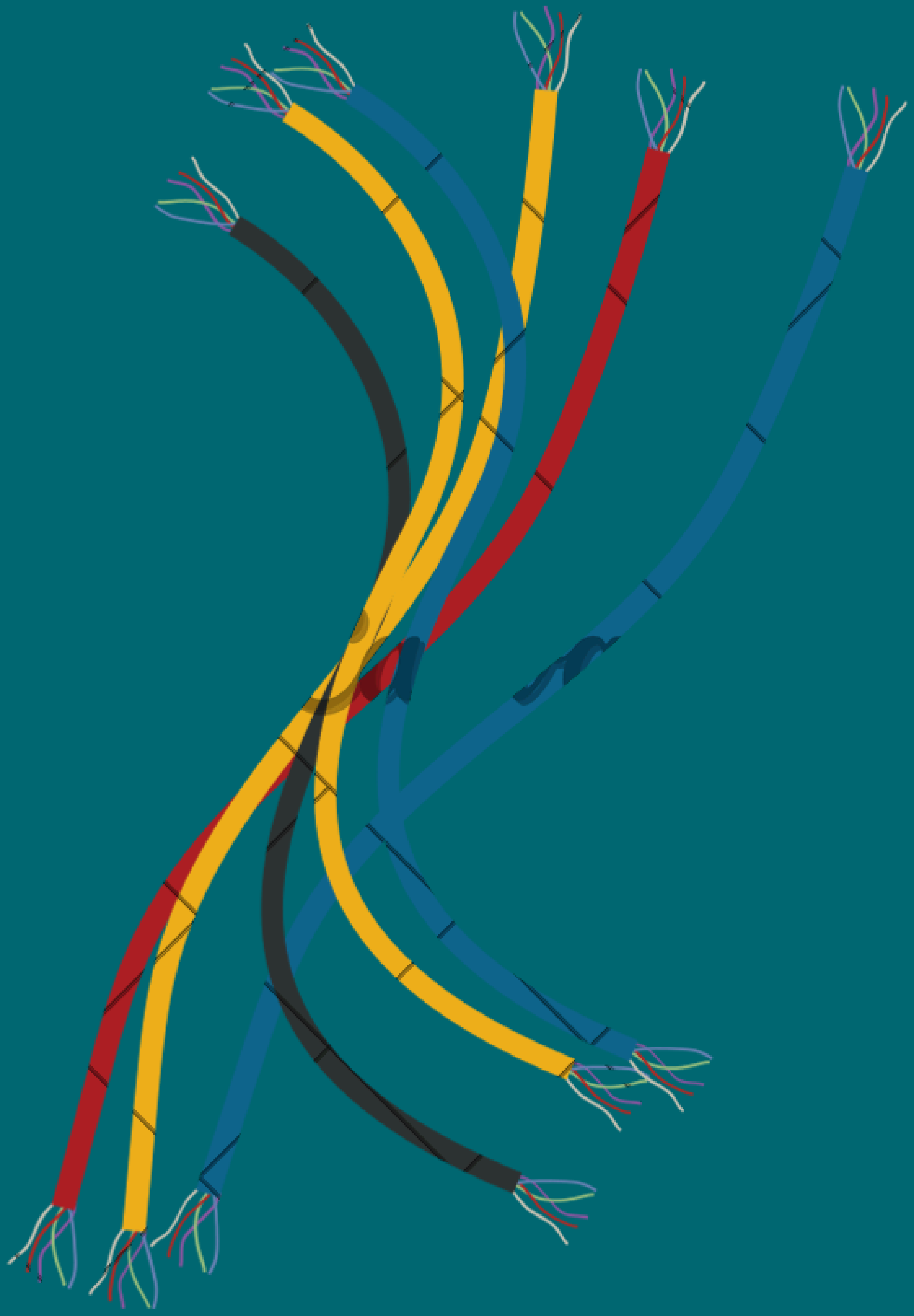
PROJECT ANALYSIS

Balloon Demonstration

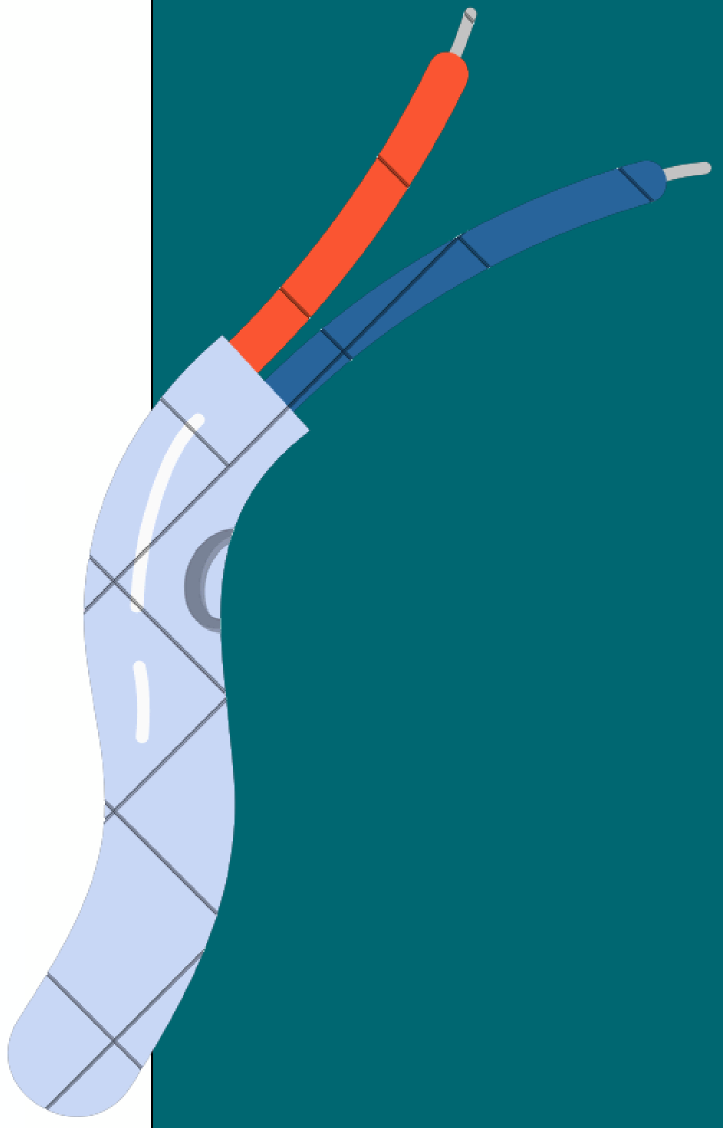
Robotic arm’s gripper holding and precisely manipulating a charged balloon

- Balloon is charged by friction -> Triboelectric series
- Balloon can be approximated as a negative point charge
- Bring another balloon (another negative point charge) near the charged balloon -> Coulombic repulsion

- The charged balloon can be used to induce a charge in a conductive material
- Ground a ball of aluminum foil and bring a charged balloon near it -> Disconnect connection with ground -> Electrons will flow from ball to ground
- Aluminum ball is induced with the opposite charge (positive) as the balloon -> Electrostatic induction
- Bring the aluminum ball near the balloon -> Coulombic attraction



Conductors and Insulators

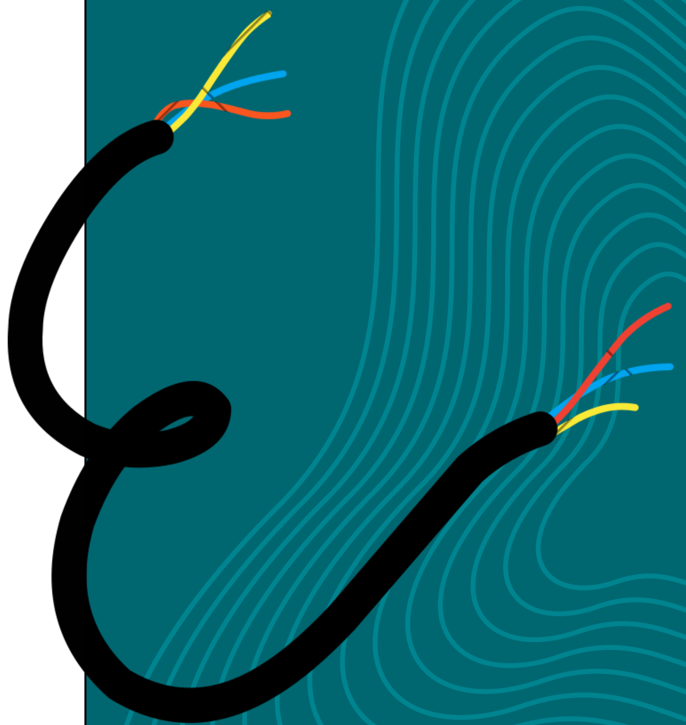


Multiple types of wires

- Wires are either braided or solid core
- Cores of these wires consist of conductive materials (e.g., copper)
- Wires are surrounded by an insulator, which prevents current from running through unintended paths
- Electrical tape, an insulator, is used to cover exposed metal to prevent any short circuits

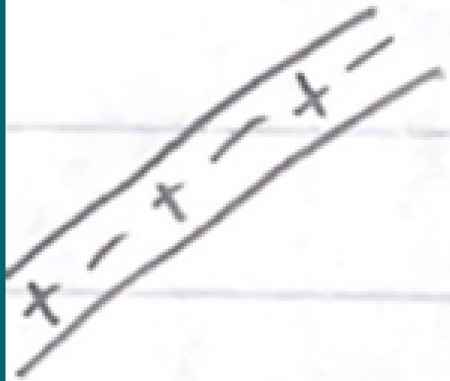
Balloon demonstration

- Balloon stores net charge uniformly throughout itself as an insulator (ideally)
- Aluminum foil ball stores net charge on its surface as a conductor



Electric Field

- Applied to a wire of uniform charge distribution, Gauss's Law allows us to determine the electric field strength at various distances from the wire
- Understanding the electric field around the wires is key because the arm contains motors that generate and interact with electric fields
- By accurately calculating the electric field strength near these, we ensure proper functionality
- Knowledge of the electric field around the wires is also essential for safety considerations.

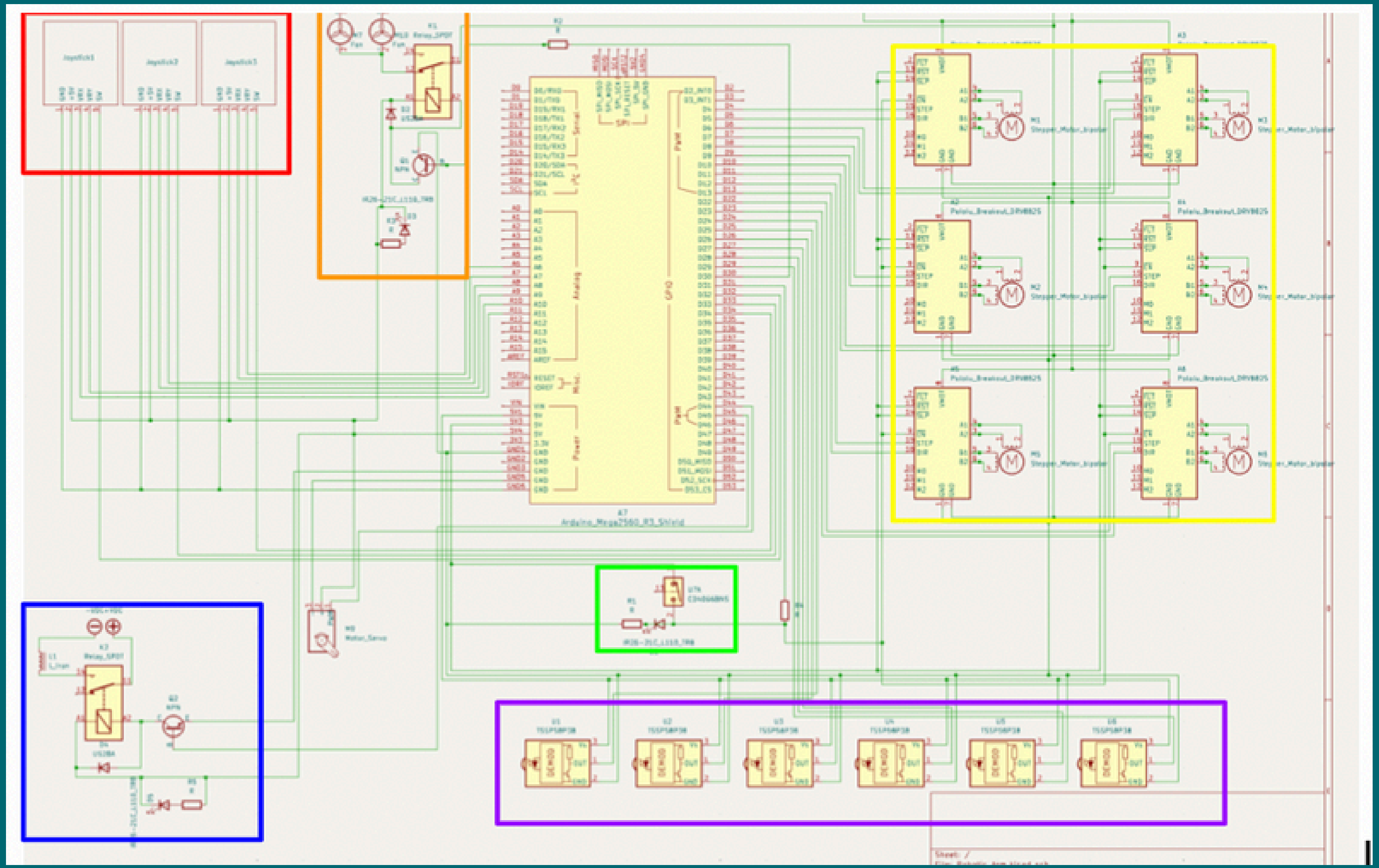


$$\vec{E} = \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0}$$

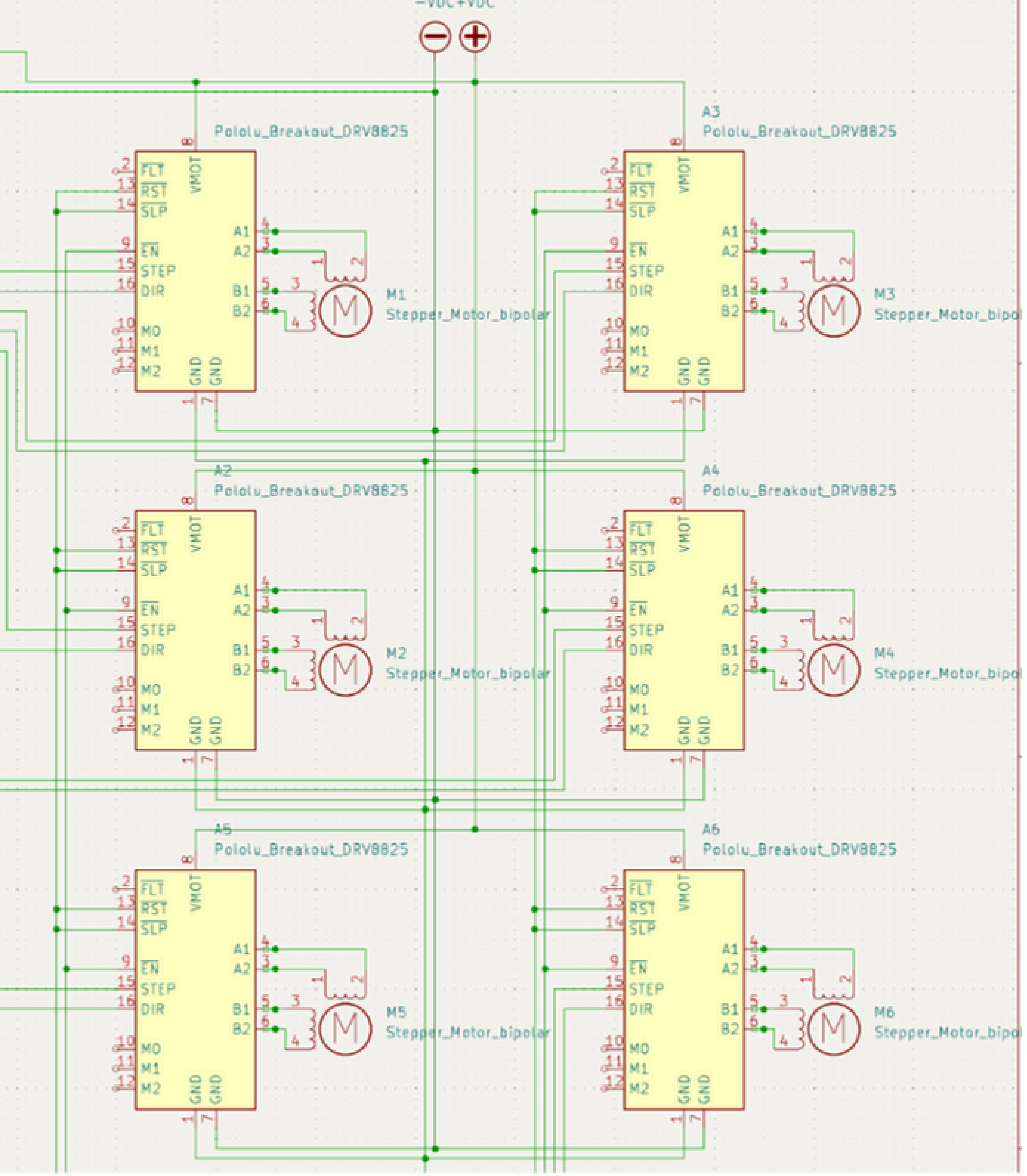
$$\vec{E} \cdot 2\pi r \ell = \frac{\lambda \ell}{\epsilon_0}$$

$$\vec{E}_m = \frac{\lambda}{2\pi r \epsilon_0} \quad \left(\lambda = \text{uniform linear charge density}\right)$$

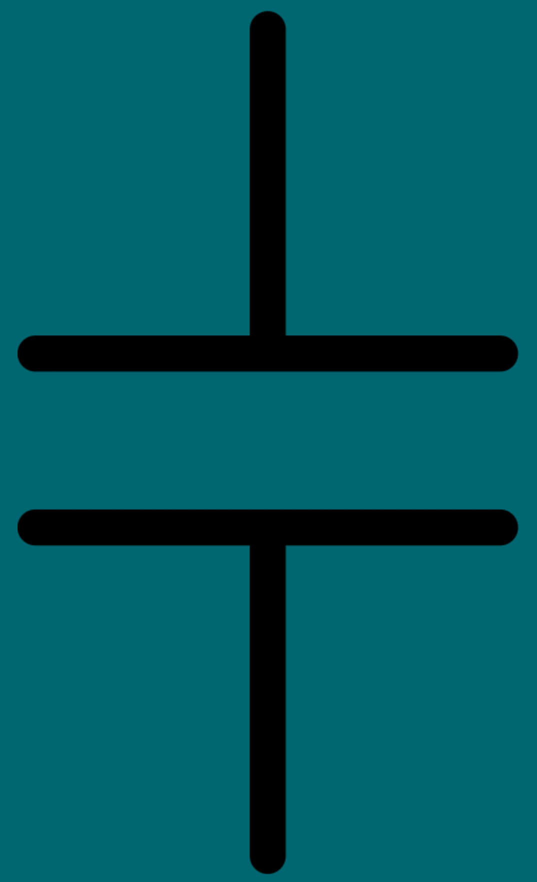
Circuit Analysis



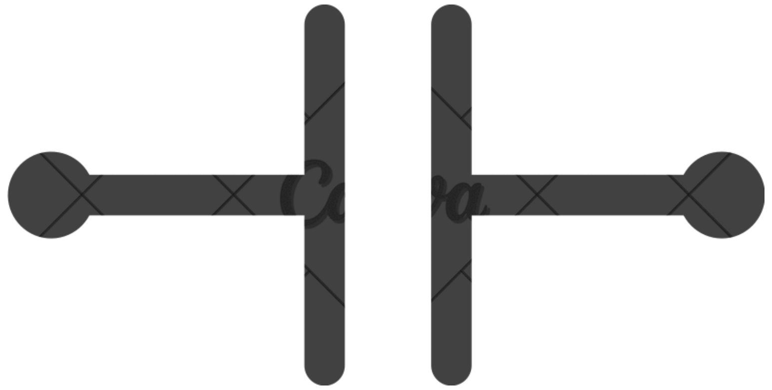
- The current of the components used must be controlled within limits to prevent overheating and failure
- This can be done by finding the voltage supplied and the resistance of the circuit
- In the case of the electromagnet, the resistance of the wire itself controls the current at different voltages
- Using a multimeter, resistance values can be measured, and these can later be compared to the current output on the power supply



VMOT Capacitor



- Functions by storing electric charge when connected to the power source and releasing it when needed to maintain voltage levels within a circuit
- Plays a crucial role in smoothing out voltage spikes and fluctuations, ensuring a steady power supply to the robotic arm and preventing damage to the motor drivers
- Connected to the power source for the six motor drivers, each containing two inductors in a parallel arrangement



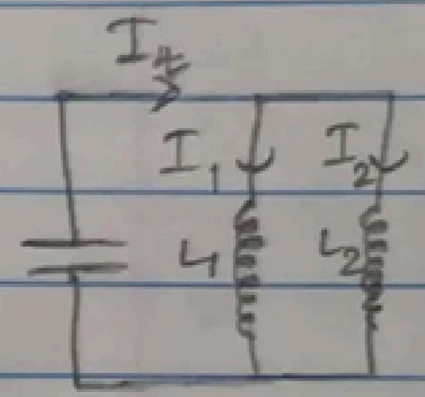
LC Series Circuit

- Each motor driver can be treated as an LC circuit
- Effective inductance of the parallel inductors:

$I_t = I_1 + I_2$

$-\frac{1}{L_{eq}}\int V\,dt = -\frac{1}{L_1}\int V\,dt - \frac{1}{L_2}\int V\,dt$

$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} \Rightarrow L_{eq} = \frac{1}{1/L_1 + 1/L_2}$



Leff = 1 / (1/L1 + 1/L2)

=> Lower magnitude than either individual inductance

- Leads to higher angular and resonant frequencies and smaller period of energy oscillation between the capacitor and the inductors

By KVL,

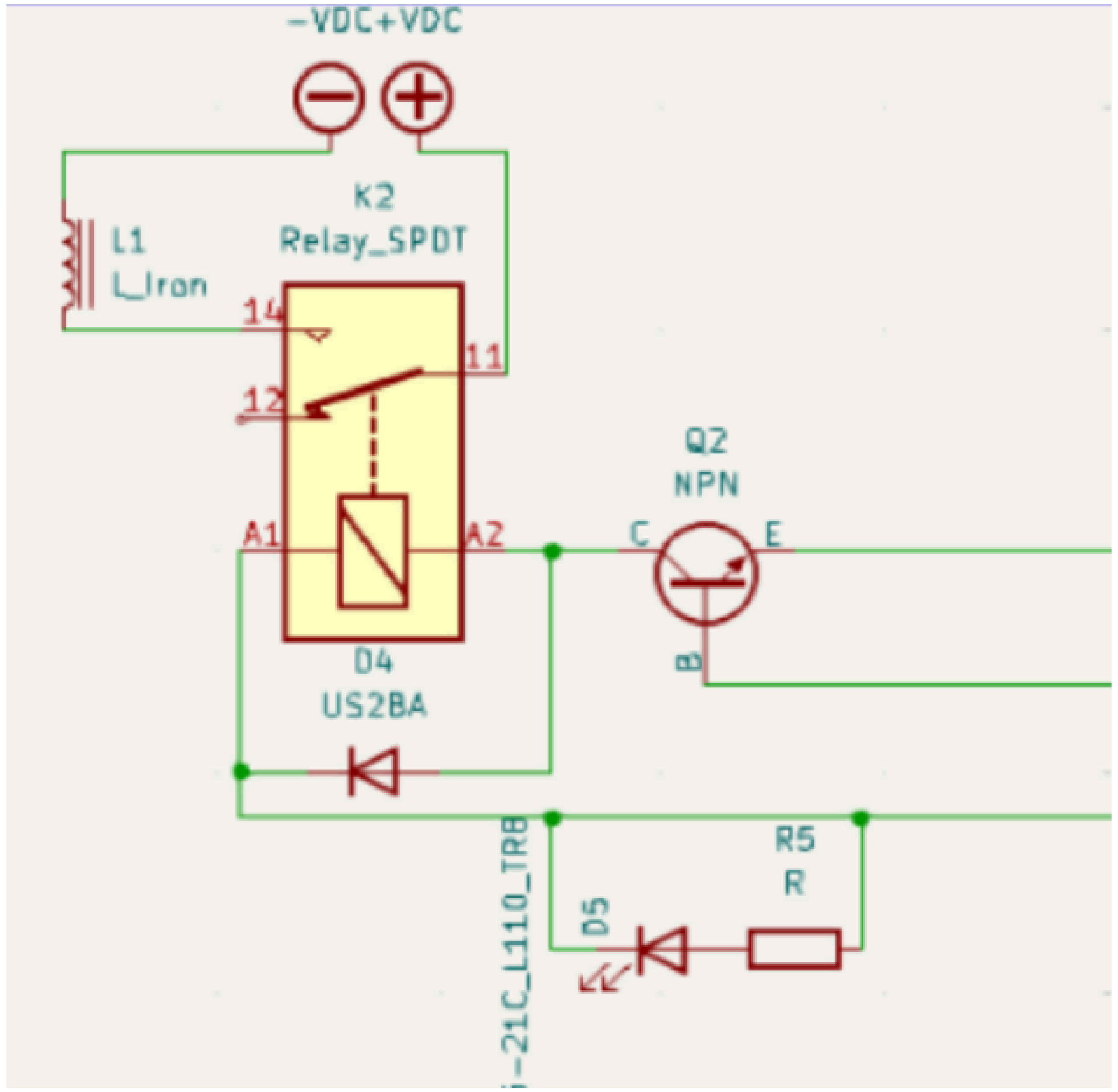
$V_c + V_L = 0$

$-\frac{q}{c} - L\frac{dI}{dt} = 0 \Rightarrow -\frac{q}{c} - L\frac{d^2q}{dt^2} \Rightarrow \frac{d^2q}{dt^2} = -\frac{1}{LC}q$

$\Rightarrow \omega = \frac{1}{\sqrt{LC}}, \quad T = \frac{2\pi}{\omega} = 2\pi\sqrt{LC}, \quad f = \frac{1}{T} = \frac{1}{2\pi\sqrt{LC}}$

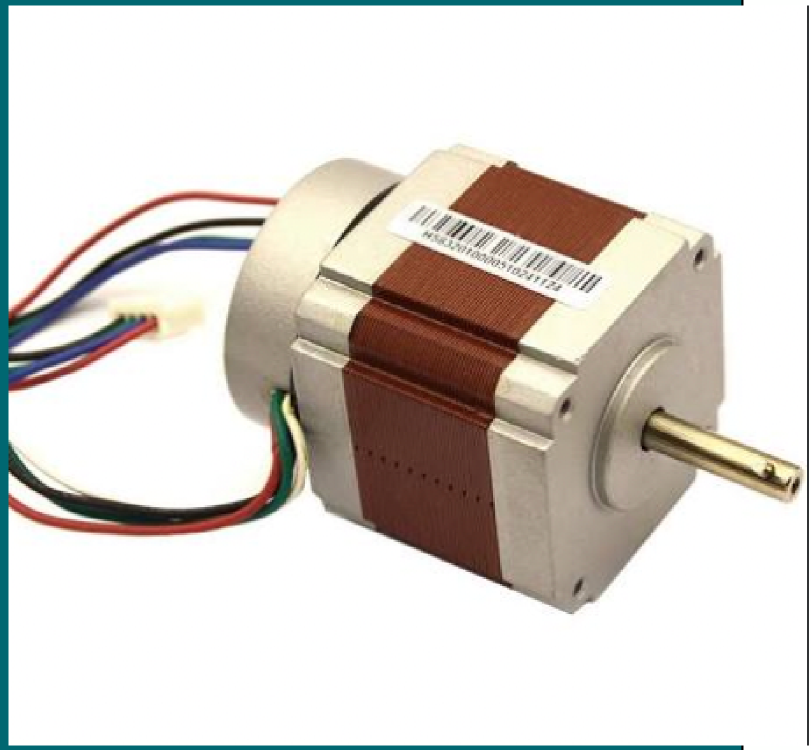
RL Parallel Circuit

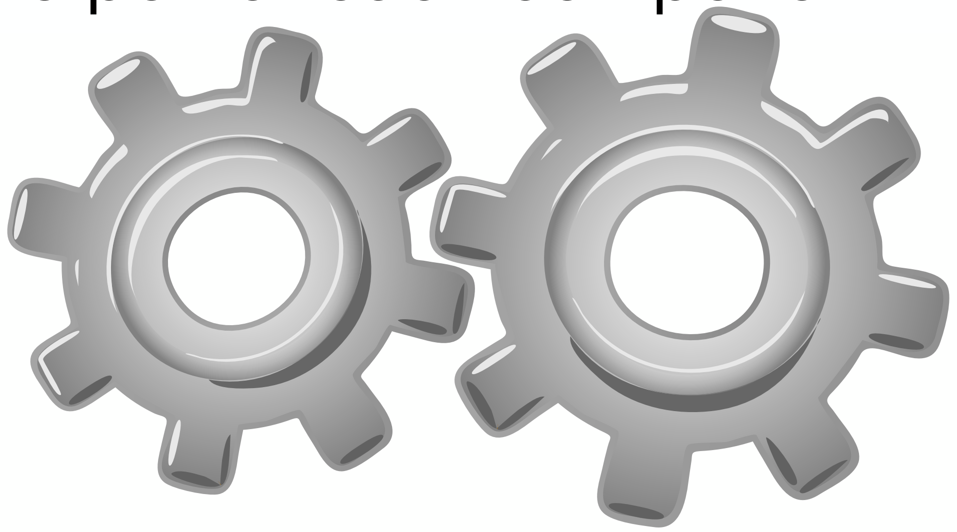
- The power source for the electromagnet is connected to a solenoid (treated as an inductor) and a resistor in parallel
- Impedance (Z) = Resistance + j * Reactance
- Z_Circuit = 1/(1/Z_Resistor + 1/Z_Inductor)
  = 1/(1/Resistance + 1/Inductive Reactance)



Motor and Fan Wiring

Many times, there is the necessity for one power source to power multiple components. For example, the power supply for the motor drivers must also drive the two cooling fans, or the E-stop must also power an LED to reveal the state of the machine. It is advised to not wire components such as fans in series, as the potential across each fan decreases.
If we want to increase the voltage each fan gets, we can't increase much before reaching dangerous voltage levels. Thus we wire them in parallel. When circuits are wired in parallel, the voltage is equivalent.
We apply this to the motors and the fans so that each component has the electric potential necessary to run. We want to find out the resistance of each component as well as the power each component has.





Motor and Fan Wiring

Let's first find out the internal resistance of each motor. This can be achieved by finding the current each motor is drawing. The power source is always set to run at 24 V. Five of the motors run at 1.1 A (verified through the multimeter) while one of them runs at 1.3 A.

Meanwhile each fan draws 0.1 A.

To find the resistance of each motor, we recall Ohm's Law, that is: I= V/R --> R= V/I

When we substitute, we get that for the five motors with a current of 1.1 A, the resistance is 21.81 Ω. The resistance for the motor that draws 1.3 A is 18.46 Ω. For each fan, the resistance up to the fan is 240 Ω.

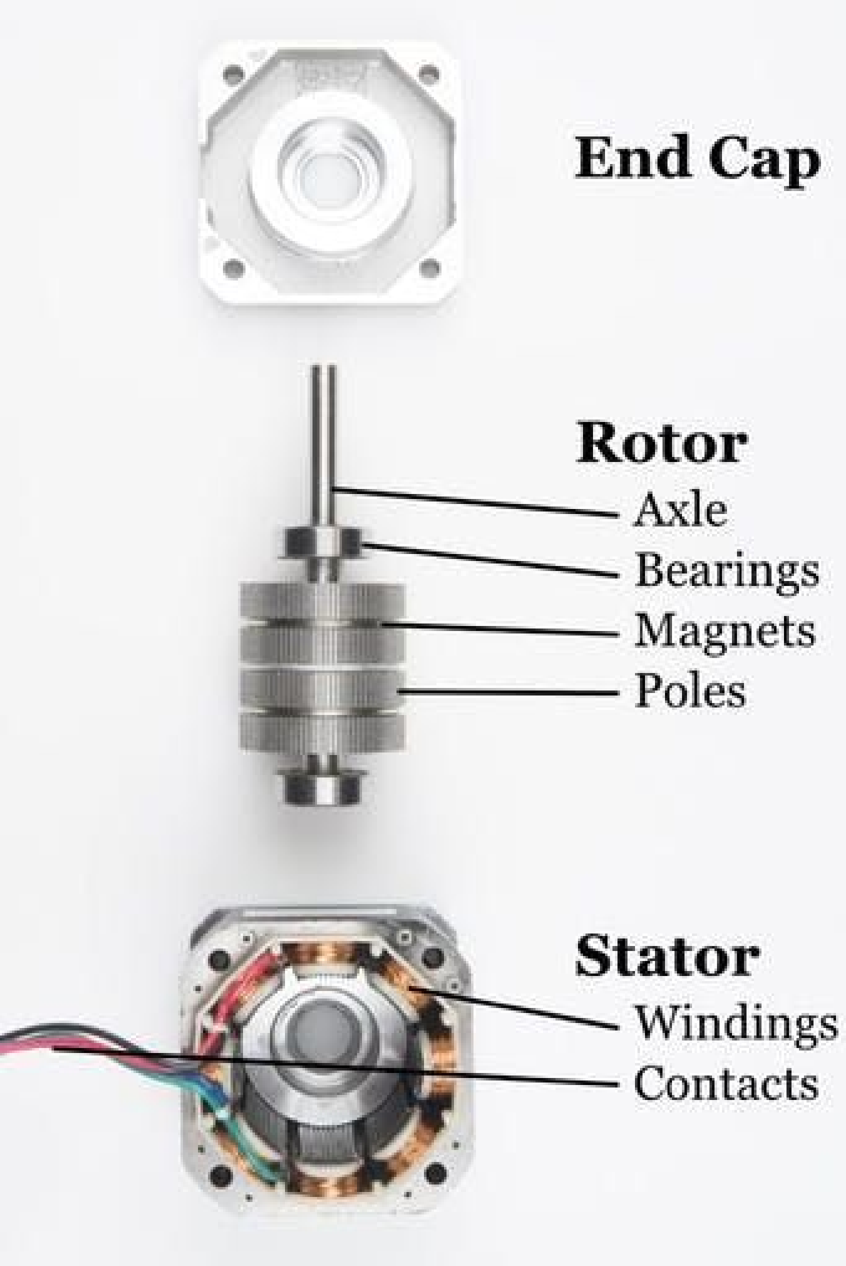
We can find the power of the motors, that is the rate of heat dissipation of each motor, as well. The formula for Power is:

P=IV

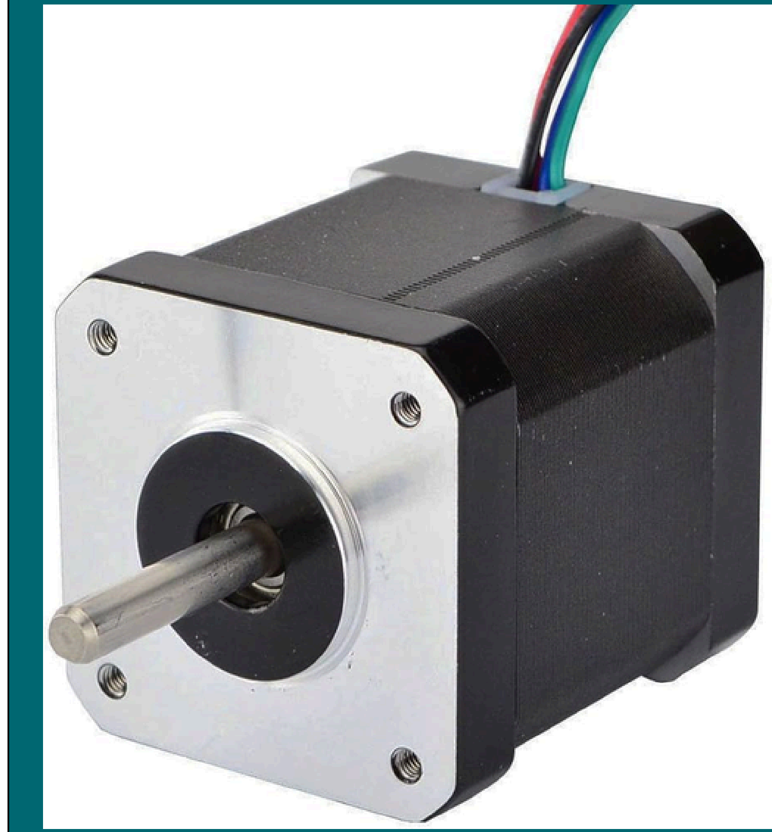
When we substitute for each component and get the following:

- Each of the five motors have a power of 1.1 A * 24 V = 26.4 W
- The one motor has a power of 1.3 A * 24 V = 31.2 W
- Each fan has a power of 0.1 A * 24 V = 2.4 W.

Lenz's Law in Stepper Motors



Stepper motors function based on quickly changing magnetic fields. Spinning the motor when not energized poses the risk of running backwards voltages that can damage stepper motor drivers. To ensure the safety of moving our stepper motors, let's consider the induced emfs generated when spinning the motor. The induced current runs in the direction that creates a magnetic field that opposes the change in the permanent magnetic field.



The motor is made up of four phases. The strength of the permanent magnets of the rotor is about 0.05 T (given by the data sheet of the motor)

Magnetic Flux & Induced EMF with Faraday's Law

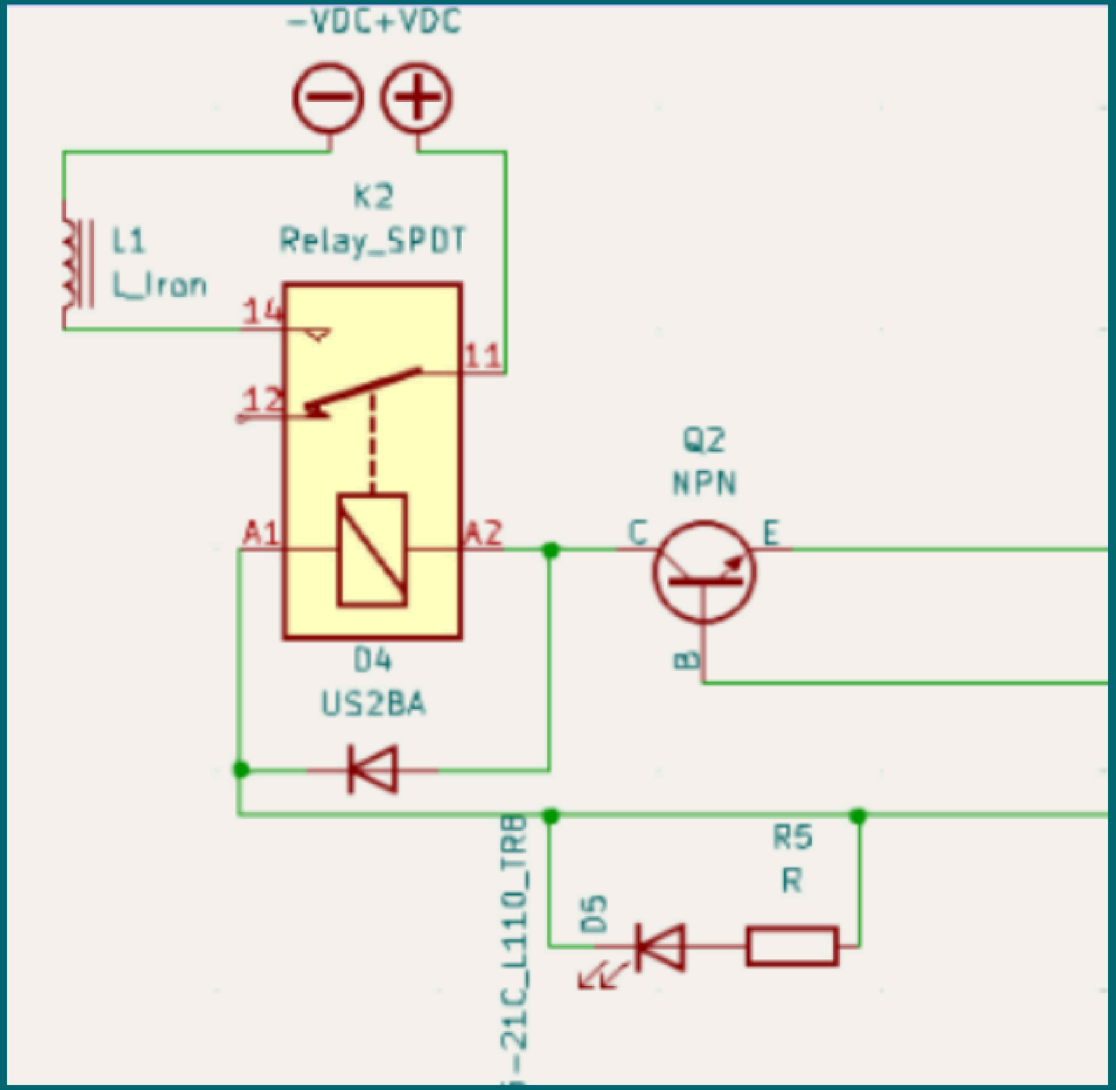
The flux of the motor is found by multiplying the magnetic field, area of the coil, and cosine of the angle between the coil and permanent magnet. The angle changes as the rotor spins, resulting in a change of magnetic flux, allowing us to calculate the induced EMF by the equation:

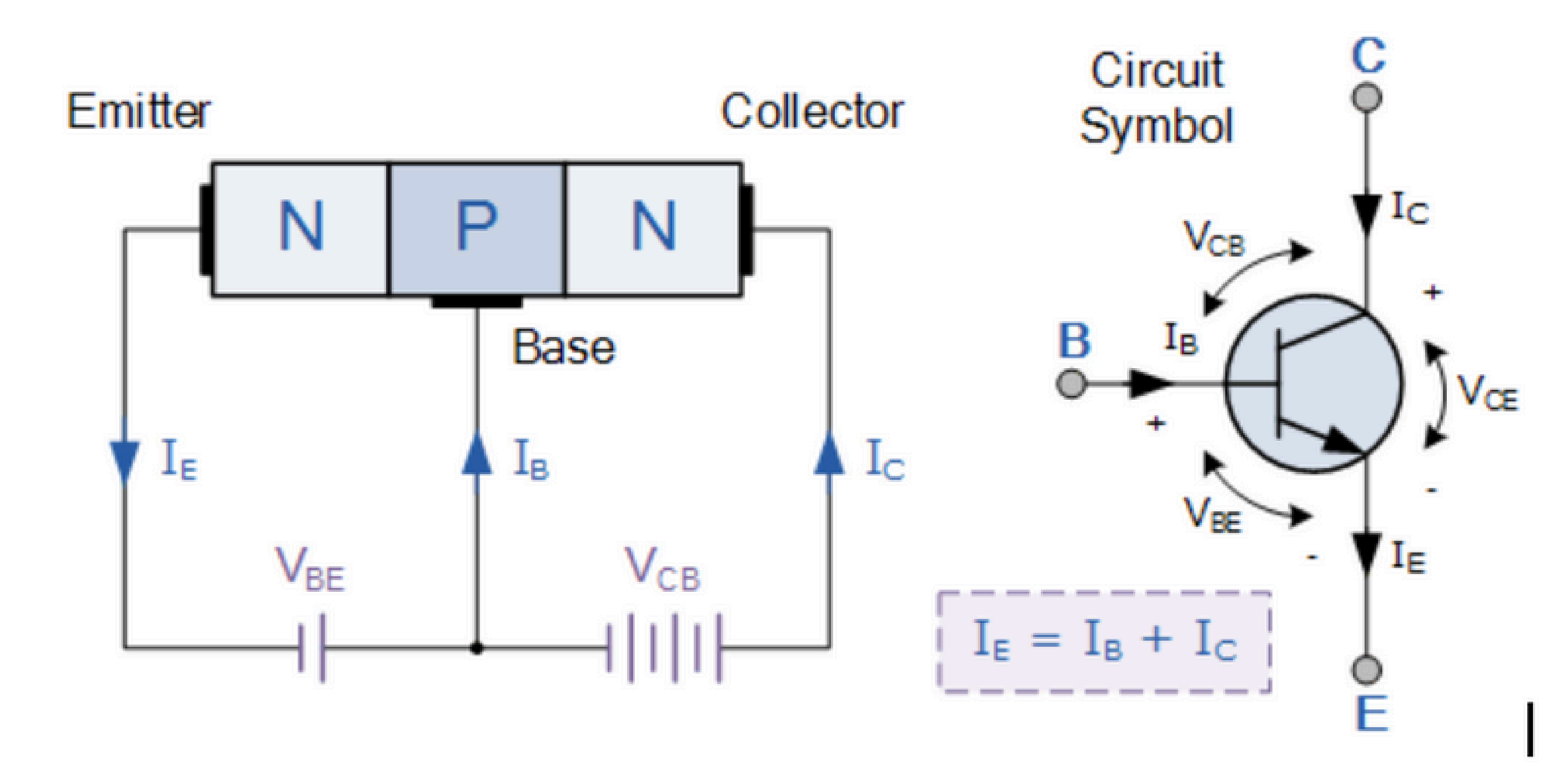
$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

Where N = 100, and dθ / dt = pi/4 rad/second
The induced emf as a result is N * B * A * sin(θ) * dθ/dt

100 * 0.05 T * 0.005^2 * pi * sin(pi/2) * pi / 4 rad/s =
= 3.08 * 10^-4 V

Accounting for all 4 phases (each with two sides): 2.47 * 10^-3
As we can see, the induced emf generated at this rotational velocity is well below the limit that would pose a risk of damage.

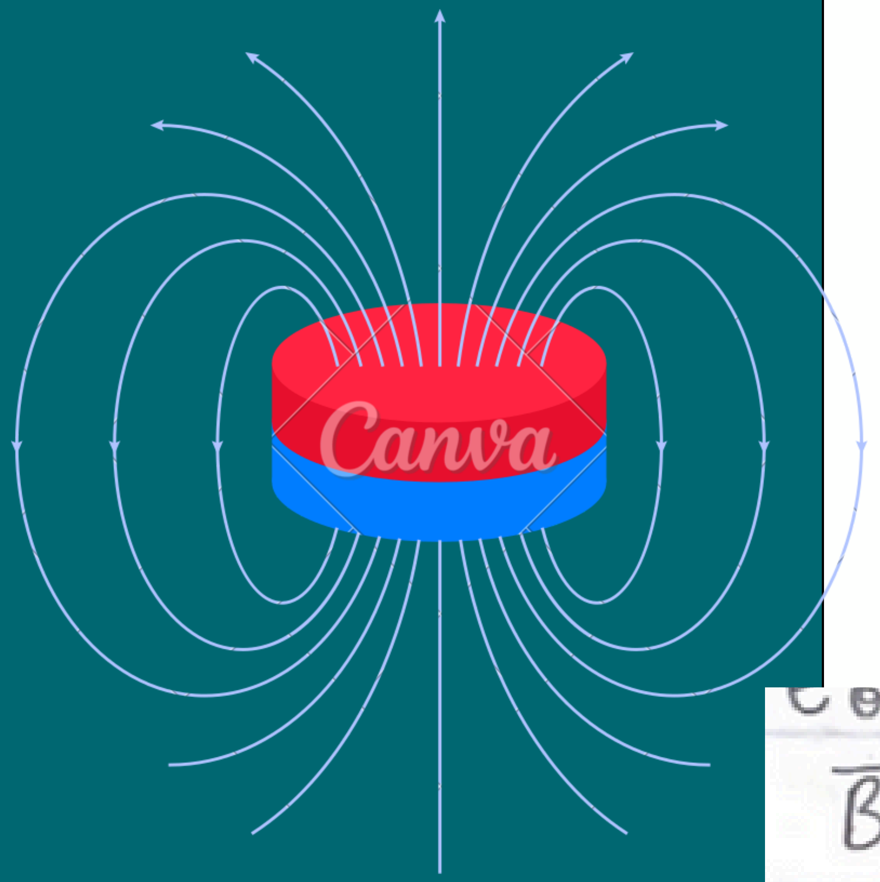


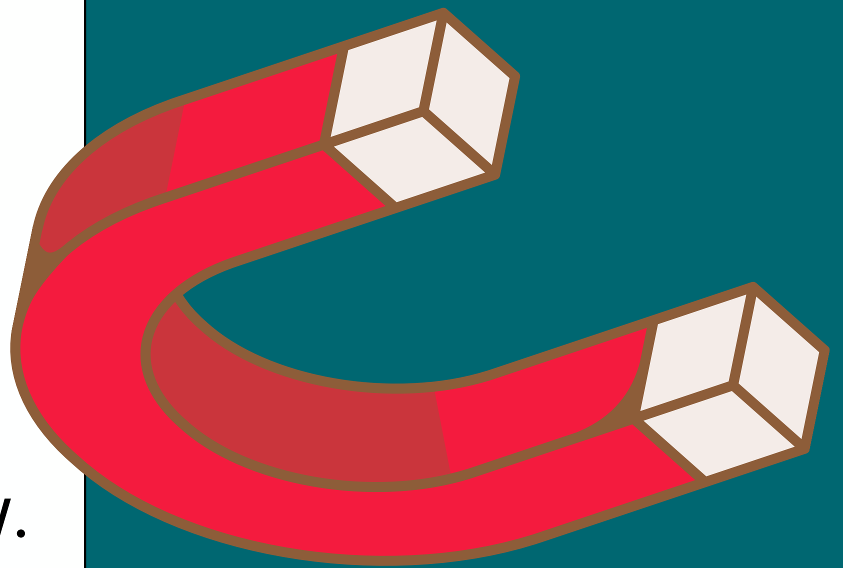


Bipolar Junction Transistors

NPN transistors, a type of bipolar junction transistor with an emitter-base junction and a collector-base junction, receive weak signals at their base and produce amplified signals at the collector end (electrons flow from emitter to the collector, so conventional current flows the opposite way). In our circuit, the Arduino's I/O pin can only provide around 20 mA, so we instead connected to the Arduino's 5V pin and used an NPN transistor as a powering relay controlled by the I/O pin.

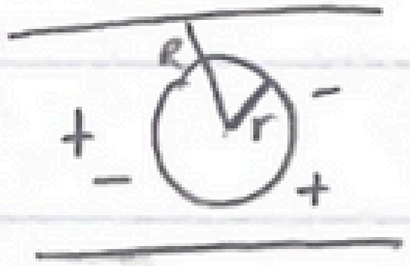
Magnetic Field





Looking at a wire, we can determine the magnetic fields at various radial distances from the center using Ampere's Law. This is important because strong enough magnetic fields can easily interfere with the proper functioning of sensitive electronic devices – of which we have a multitude in the circuitry of our robotic arm.

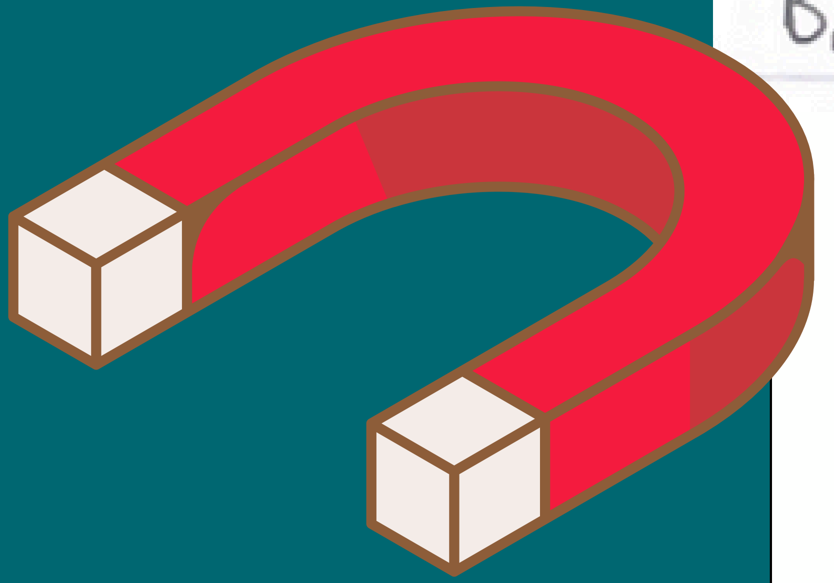
$$\vec{B}_{in} \Rightarrow \oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

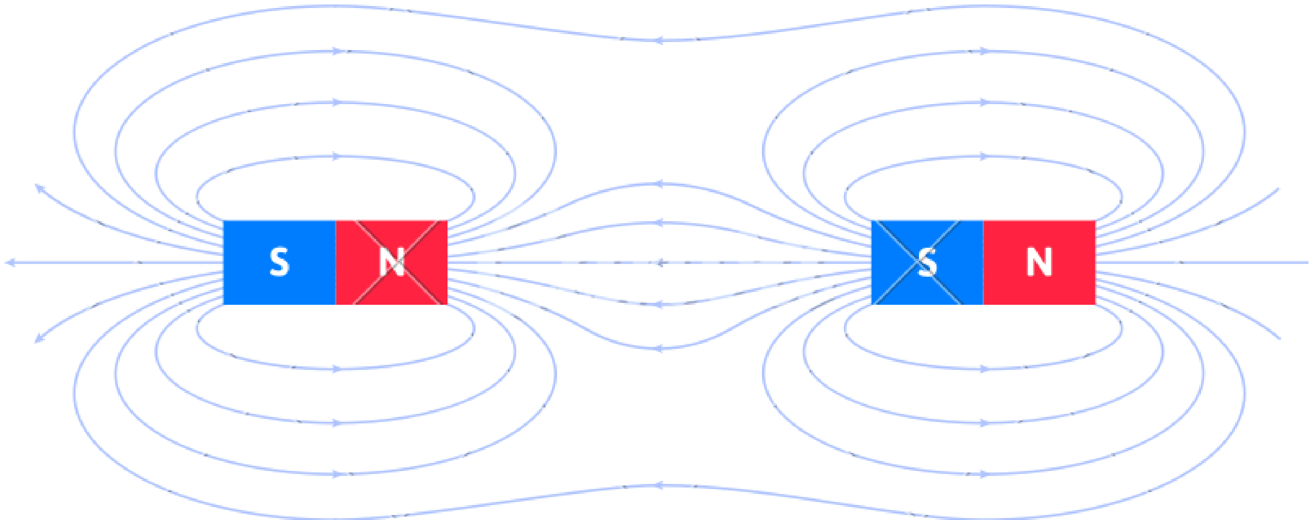


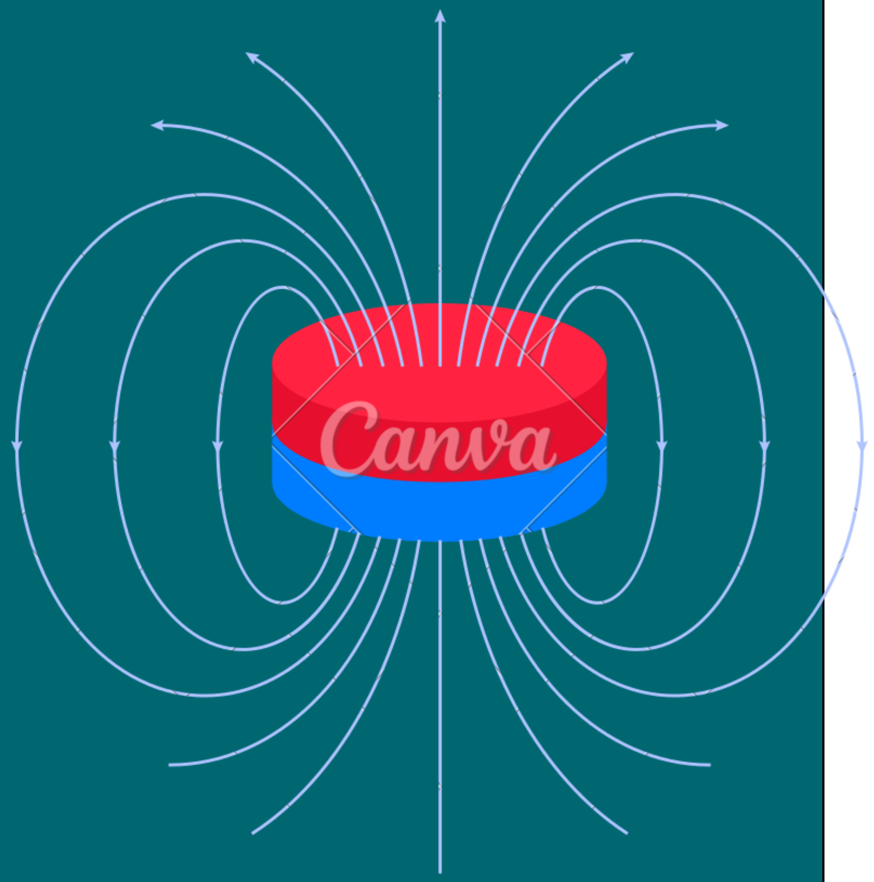
$$B \cdot 2\pi r = \mu_0 I \frac{r^2}{R^2} \Rightarrow \vec{B}_{in} = \frac{\mu_0 I r}{2\pi R^2}$$

(constant J)

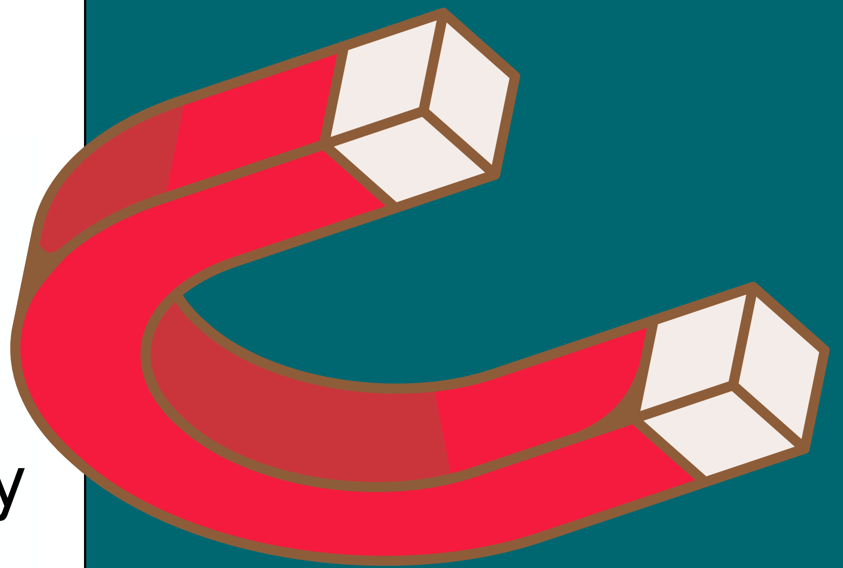
$$\vec{B}_{out} \Rightarrow \oint \vec{B}\, d\vec{l} = \mu_0 I_{enc} \Rightarrow \vec{B}_{out} = \frac{\mu_0 I}{2\pi r}$$







Electromagnet



Electromagnets consist of coils of wire wrapped around a core material, which becomes magnetized when current flows through the wire. These electromagnets are extremely important for the robotic arm as it enables the arm to grasp objects with the gripper. By controlling the strength and polarity of the magnetic field, electromagnets allow the arm to securely grip objects.

Magnetic Field

The structure of an electromagnet can be thought of as a solenoid, and the solenoid calculations apply to it.

$$U_B = \frac{1}{2}LI^2 = \frac{1}{2}\left(\frac{\mu_0 N^2 A}{\ell}\right)I^2 = \frac{1}{2}\left(\mu_0 \frac{N}{\ell} I\right)^2 \frac{1}{\mu_0} A\ell = \frac{B^2 A \ell}{2\mu_0}$$

$$\frac{U_B}{Vol} = \frac{B^2}{2\mu_0}$$

ℓ

$$W = \int F_B \cdot dx = U_B = \int \frac{B^2}{2\mu_0} A\,dx \rightarrow F_B = \frac{B^2 A}{2\mu_0}$$

x

$$\boxed{F_B = \frac{\mu_0 N^2 I^2 A}{2x^2}} \rightarrow \boxed{F_B = \frac{\mu_0 \mu_r N^2 I^2 A}{2x^2}}$$

$(x >> \ell)$

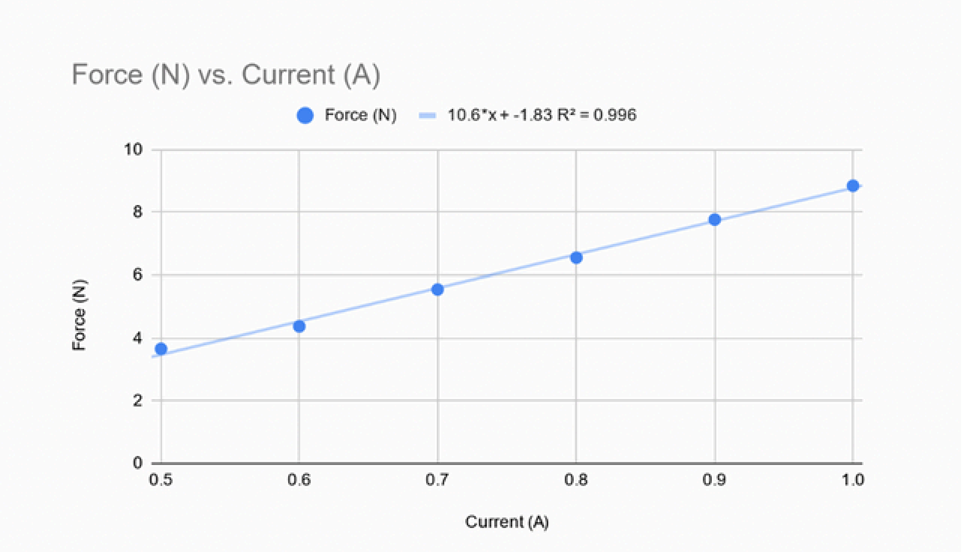
Electromagnet (cont.)

Material Permeability

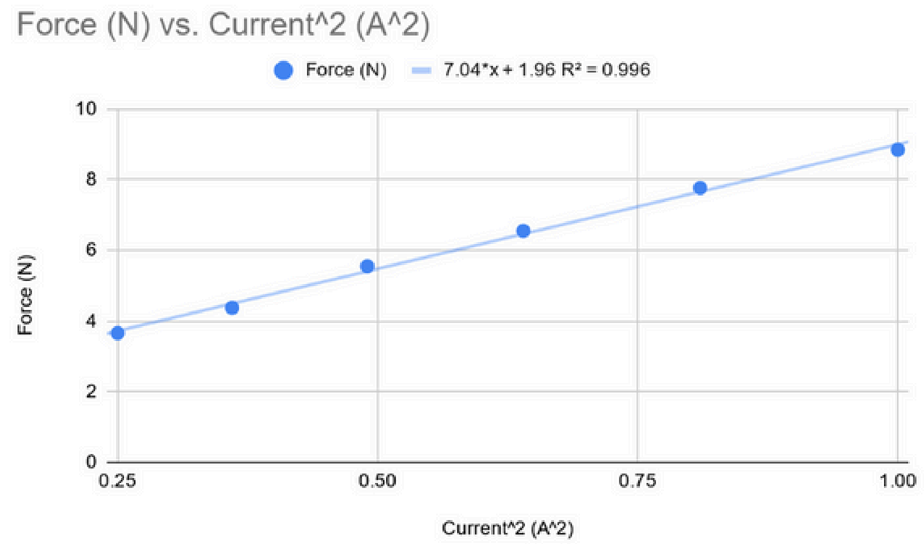
We can use the electromagnet to pull a metal bar on a scale until the bar is pushed off to measure the mass the electromagnet can lift. By noting and graphing the current and force, we can find the material of our core.

Current (A)	Mass (kg)	Force (N)	Current^2 (a^2)
0.5	0.373	3.65913	0.25
0.6	0.446	4.37526	0.36
0.7	0.566	5.55246	0.49
0.8	0.668	6.55308	0.6[illegible]
0.9	0.792	7.76952	0.81
1	0.902	8.84862	1

nonlinearized



linearized



Electromagnet (cont.)

Solving for Ur (relative permeability) and plugging the line of best fit's coefficient.

$$F = I L \times B$$

$$B = \frac{1.257 \cdot 10^{-6} \cdot U_r \cdot I \cdot N}{L}$$

$$F = 1.257 \cdot 10^{-6} \cdot U_r \cdot I^2 \cdot N$$

$$U_r = \frac{F}{1.257 \cdot 10^{-6} \cdot I^2 \cdot N}, \quad \text{where: } \frac{F}{I^2} = 7.04, \; N = 1100$$

$$= 5091.49 \sim \boxed{5000}$$

Comparing our value to a table of materials with different permeability constants:

Electromagnet (cont.)

Comparing our value to a table of materials with different permeability constants:

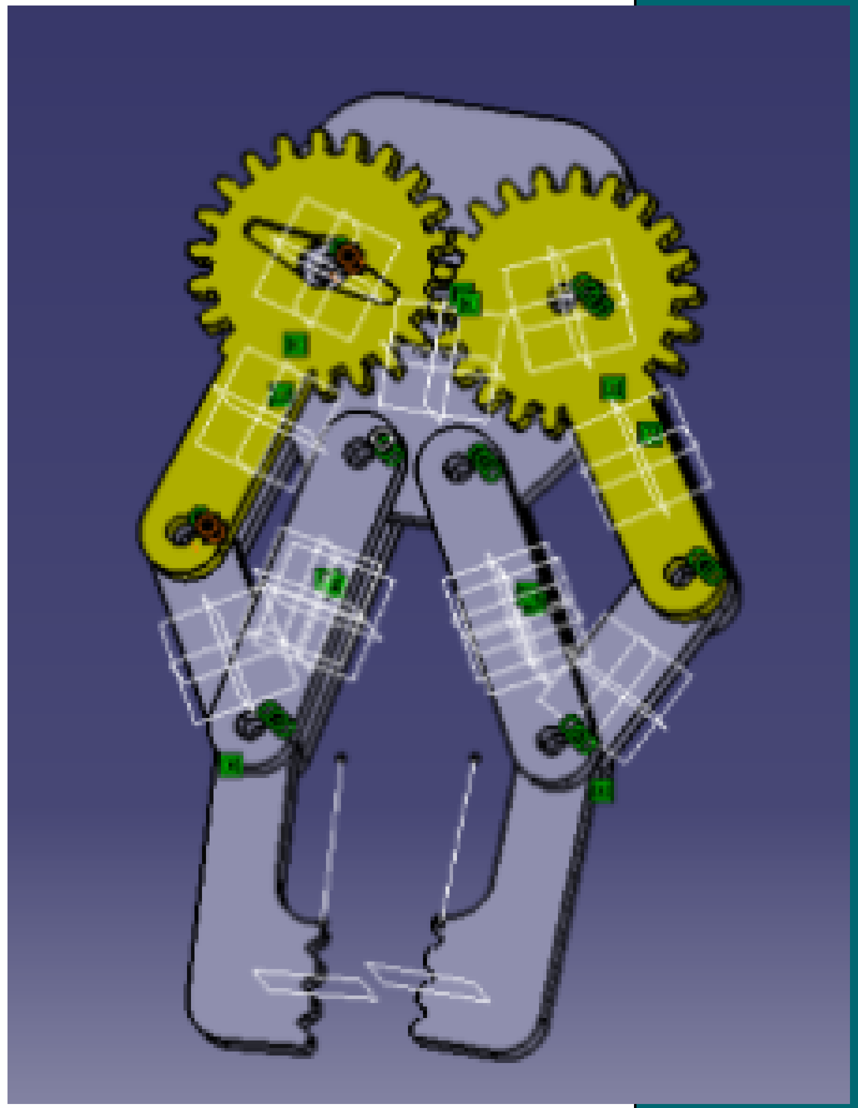
Mu-metal		20 000[13]
Cobalt-iron (high permeability strip material)		18 000[14]
Iron (99.8% pure)		5000[9]
Electrical steel		2000 - 38000[5][15][16]
Ferritic stainless steel (annealed)		1000 – 1800[17]
Martensitic stainless steel (annealed)		750 – 950[17]

Our analysis reveals that the material of our core is 99.8% pure iron.

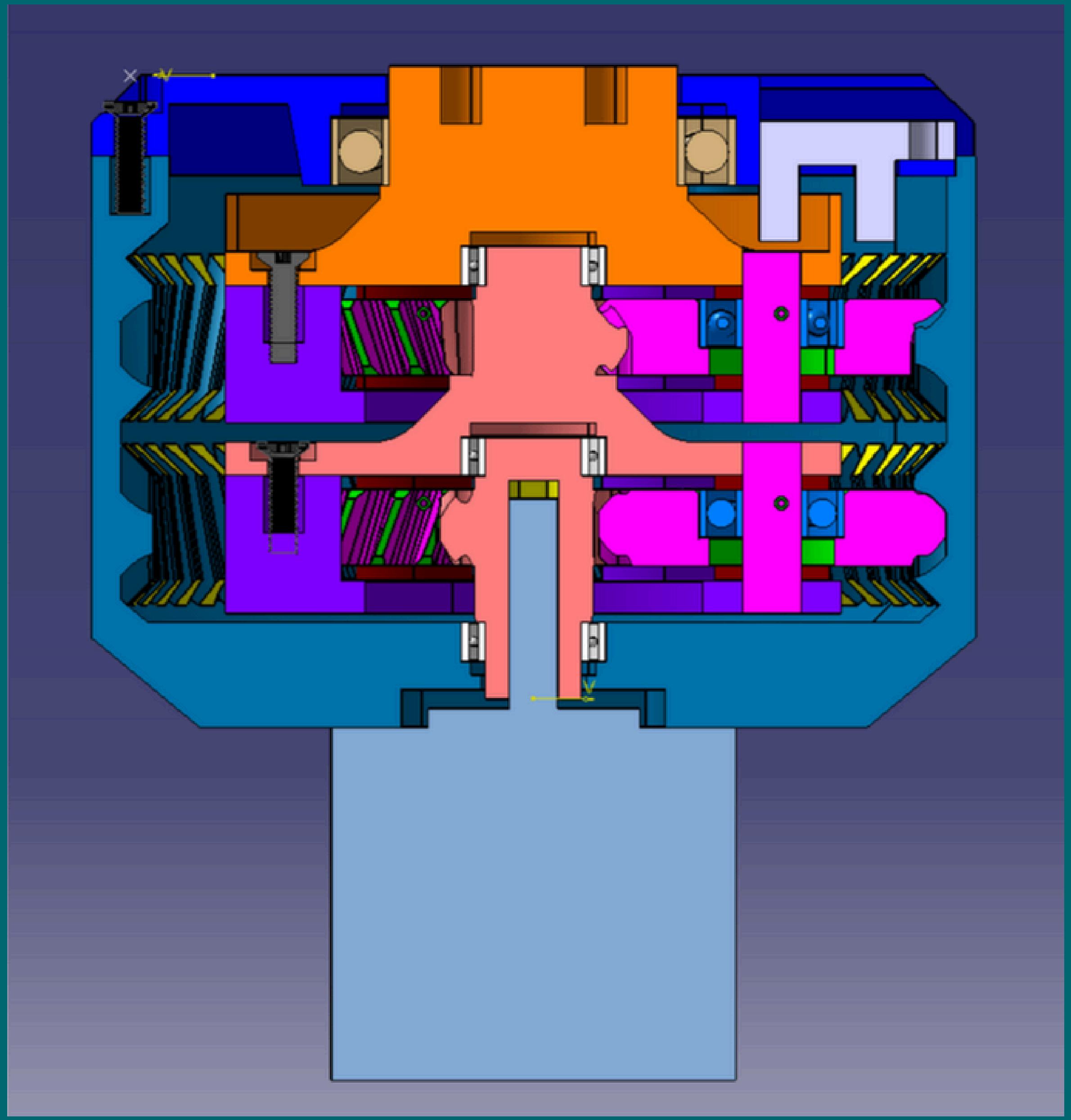
Assumptions and Limitations

Assumptions were made in previous calculations regarding various aspects of the robotic arm.

- For the electromagnet, the assumption was made that it operates under perfect conditions, including the absence of internal resistance in the wire, allowing for accurate determination of the coefficient of permeability.
- Additionally, it was assumed that the motor drivers are drawing maximum current, although this is unlikely based on our experience working with the motors.
- The arm has functional limitations, including slow movement speed, which can be attributed to under-powered motor drivers.
- The arm's load capacity is also limited, affecting its ability to carry heavy objects.
- Finally, the arm draws a significant amount of power and requires two power supplies to operate properly, which adds to its operational complexity.



Sources of Error



Some sources of error in the project analysis include:

- In the balloon demonstration, we assume that there is a uniform charge on the balloon, however uneven charge distribution on the balloon can affect the precision of the demonstration.
- For electric fields, we assume that there is a uniform charge distribution along the wire, which may not be true.
- In the motor driver, variations in the inductances (due to mutual inductance and resistance of real inductors) can affect calculations.
- For the circuit analysis (i.e., LC Series circuit and RC Parallel circuit), inaccurate calibration of the multimeter could have lead to incorrect resistance and current measurements.
- Errors in measuring the current drawn by the motors and fans can lead to incorrect resistance and power calculations.
- In the Bipolar Junction Transistor, variability in the signal strength from the Arduino’s I/O pin can affect the transistor.
- For the electromagnet, external magnetic fields can interfere with the measurements and calculations of the magnetic fields around the wires.

SOCIAL IMPLICATIONS

Facilitation of extensive manual labor

- Manufacturing
- Agriculture

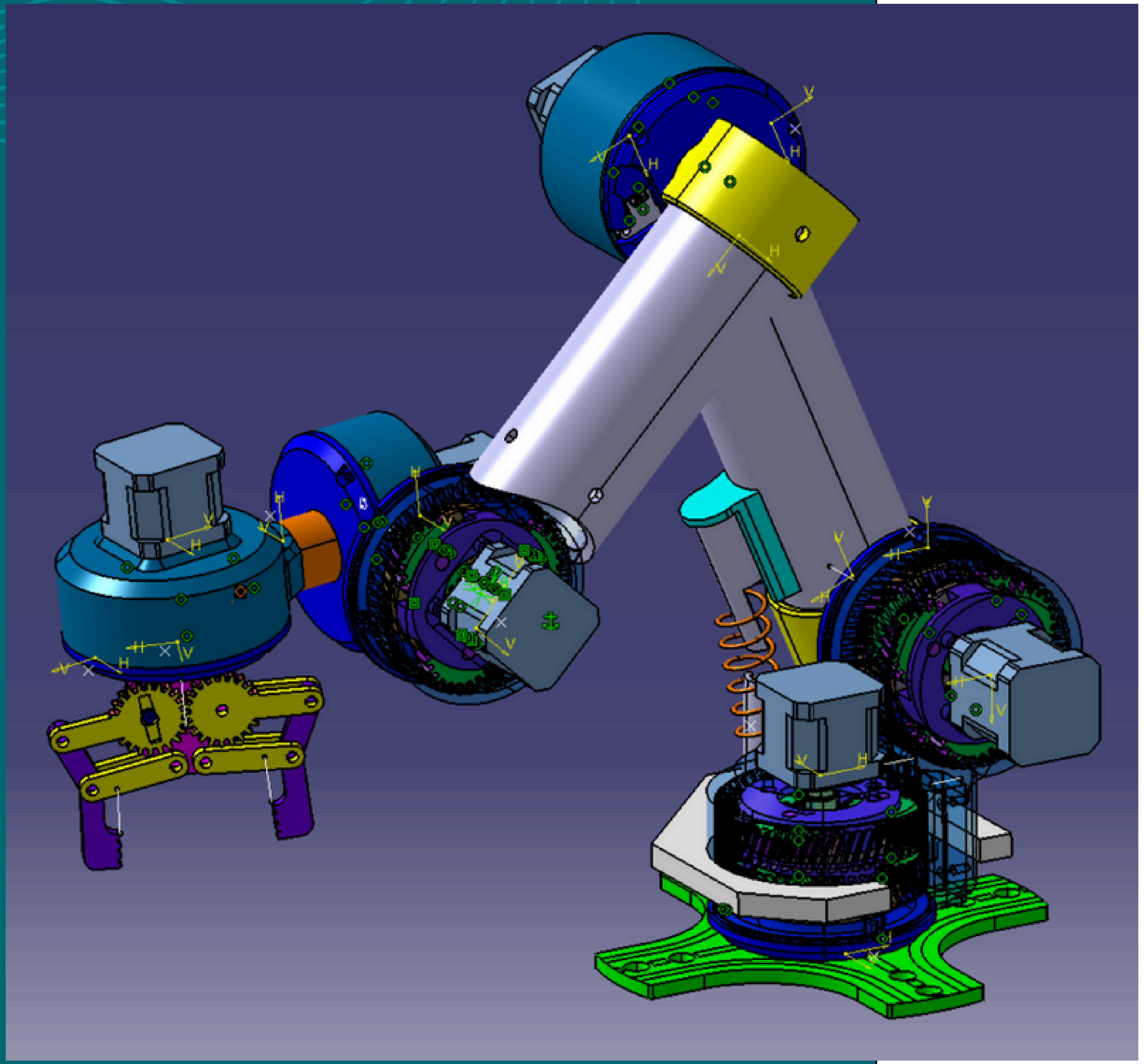
Facilitation of precision-centric labor

- Surgery
- Quality control

Facilitation of dangerous labor

- Defense
- Mining

Conclusion



BRANDONW -- final thoughts

- The BRANDONW robot arm incorporates various concepts from our class, showcasing its flexibility and versatility.
- Electrostatics concepts are demonstrated by the arm, including the induction of charge through friction by rubbing a cloth on a balloon.
- Additionally, the arm can induce charge without contact by grounding an object and holding a charged object near it, allowing for the creation of charged aluminum balls.
- The arm also explores conductors and insulators within its design.
- Circuit analysis of the robot's wiring allows exploration of resistance, current, and voltage using Ohm's Law, particularly concerning motors and fans.
- Power consumption of each component is examined, with a capacitor included in the circuit to prevent power spikes from damaging the controller.
- The capacitor is also viewed as an LC circuit, providing insights into its behavior.
- The circuit analysis also involves exploration of the Bipolar Junction Transistor (BJT) and the inductors present.
- The electromagnet within the arm is treated as a solenoid, allowing for the derivation of its magnetic field.
- The electromagnet has its own power supply and uses a transistor to toggle its state on and off, demonstrating its controlled operation.

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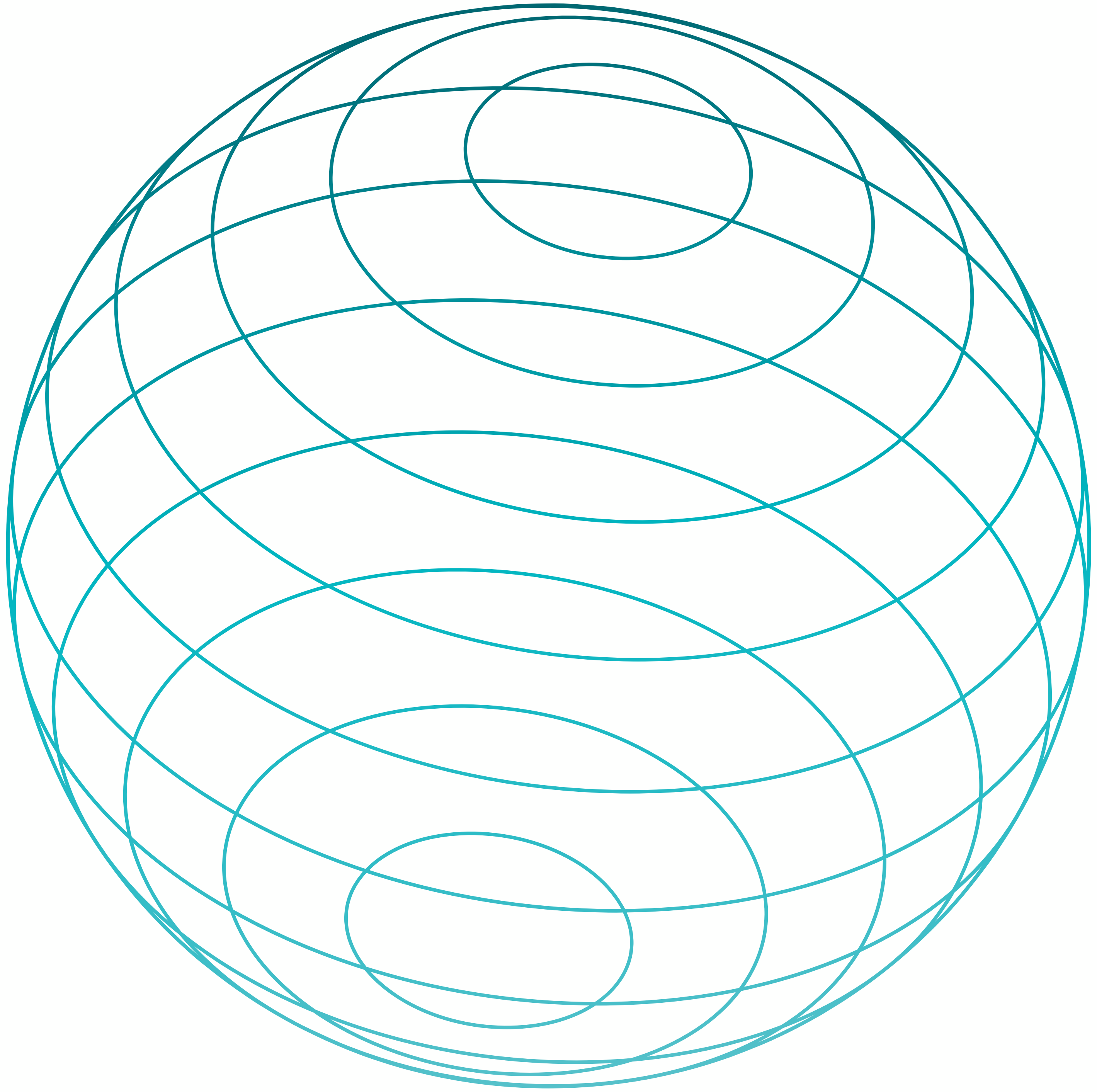

thank you!