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(Research Article)

Data analysis and visualization of electric vehicle engineering

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Abstract

We have visualized data using Excel to understand the relationship between battery chemistries and capacity. Examined Python code for tuning a Proportional – Integral – Derivative (PID) controller to understand its role in improving control accuracy. The challenges and benefits of PID tuning are discussed, highlighting the importance of precise tuning for optimal performance, efficiency, and safety. Analysing the impact of various battery form factors, including cylindrical, pouch, and prismatic options, on system cost, safety, and durability. Furthermore, the paper explores design trade-offs in electric vehicle development, emphasizing the need for balancing competing parameters such as performance, durability, and cost-effectiveness. The characteristics of various battery form factors (cylindrical, pouch, and prismatic) and Light Detection and Ranging (LiDAR) sensors (mechanical, solid-state, and hybrid) are compared, providing insights into their suitability for different applications. Overall, this article offers a comprehensive overview of the intricate relationships between battery chemistries, PID controllers, and design trade-offs in the development of efficient and sustainable electric vehicles. Conducted a comprehensive cost-benefit analysis for different LiDAR sensor models, comparing mechanical scanning, solid-state, and hybrid LiDAR sensors, with a focus on durability, scanning speed, and cost implications. Beside the aforementioned, we have also presented technical findings in a concise format using tables, aiding the engineering division in making informed decisions for various projects.

Keywords: Electric Vehicles; Battery; PID controllers; LiDAR Sensors; Design Trade-offs

1. Introduction

If you were buying a car in 1899, you would have had three major options to choose from. You could buy a steam powered car, typically relying on gas powered boilers, these could drive as far as you want provided you also wanted to lug around extra water to refuel and did not mind waiting 30 minutes for your engine to heat up. Alternatively, you could buy a car powered by gasoline. However, the internal combustion engine in these models required dangerous hand-cranking and emitted loud noises and foul-smelling exhaust while driving. So, your best bet was probably option number three, a battery powered electric vehicle. These cars were quick to start, clean and quiet to run and if you live somewhere with access to electricity, easy to refuel overnight. If this seems like an easy choice, you are not alone. By the end of the 19th century, nearly 40% of American cars were electric. In cities with early electric systems battery powered cars were a popular and reliable alternative to their occasionally exclusive competitors, but electric vehicles had one major problem- Batteries. Early car batteries were expensive and inefficient. Many inventors including, Thomas Edison tried to build batteries that stored more electricity. Others even built exchange stations in urban areas to swap out dead batteries for charged ones. But these measures were not enough to allow electric vehicles to make long trips. And at over twice the price of a gas-powered car, many couldn't afford these luxury items. At the same time oil discovery lowered the price of gasoline and new advances made internal combustion engines more appealing. Electric starters removed the need for hand-cranking, mufflers made engines quieter and rubber engine mounts reduced vibration. In 1908, Ford released the Model T; A cheap, high-quality gas-powered car that captured the public imagination. By 1915 the percentage of electric cars on the road had plummeted. For the next 55 years' internal combustion engines ruled the

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roads. Aside from some special purpose vehicles, electric cars were nowhere to be found. However, in the 1970s, the tide began to turn. US concerns about oil availability, renewed interest in alternative energy sources and studies in 1980s linking car emissions with smog in cities like Los Angeles, encouraged governments and environmental organisations to reconsider electric vehicles. At this point, car companies had spent decades investing in internal combustion engines without devoting any resources to solving the century old battery problem. But other companies developing increasingly efficient batteries to power a new wave of portable electronics. By the 1990s, energy dense nickel metal hydride batteries were on the market, soon followed by lithium-ion batteries. Alongside regulatory mandates by California to reduce smog, these innovations sparked a small wave of new electric vehicles, including hybrid cars. Hybrids are not true electric vehicles; their nickel metal hydride batteries are only used to optimise the efficiency of gas burning engines. But in 2008, Tesla motors went further, grabbing the attention of consumers, automakers, and regulators with its lithium-ion powered Roadster. This purely electric vehicle could travel more than 320 km on a single charge, almost doubling the previous record. Since then, electric vehicles have vastly improved in cost, performance, efficiency and availability. They can accelerate much faster than gas powered sports cars, and while some models still have a high upfront cost, they reliably save the driver’s money in the long run. Why do they have a high upfront cost? How can they save the driver’s money in the long run? This paper will be covering all these why’s and how’s of electric vehicles providing us a deeper insight into these electrifying vehicles.

2. Material and methods

2.1. EV battery chemistries

In electric vehicles (EVs), choosing the right battery chemistry involves balancing energy density, weight, cost, safety, and lifespan. Each option presents its own set of trade-offs.

- **Lithium-Ion (Li-ion)** dominates due to high energy density and a good balance of storage versus weight, offering long cycle lives. However, they can be costlier and require meticulous management to ensure safety. Also commonly known as the future battery. [1]
- **Lithium Iron Phosphate (LiFePO4)** excels in safety and thermal stability, with a longer lifespan and more charge cycles than Li-ion. The trade-off comes in slightly lower energy density, affecting range and vehicle weight.
- **Nickel-Metal Hydride (NiMH)**, previously favoured in hybrids, is durable and cost-effective but suffers from lower energy density, leading to heavier battery packs that can impact vehicle design and efficiency.
- **Solid-State batteries** promise higher energy density, faster charging, and superior safety with a solid electrolyte, reducing leakage and thermal risks. Their current limitations are higher costs and technical challenges in mass production. Used by automotive mammoths such as Tesla and BYD.
- **Lithium Polymer (LiPo)** batteries offer design flexibility and a lightweight structure, making them suitable for smaller EVs, drones, and electric bikes. However, they share similar cost and safety concerns as Li-ion batteries. [1]

Manufacturers must weigh these factors to select a chemistry that aligns with their goals, whether it's maximizing range, prioritizing safety, or managing costs.

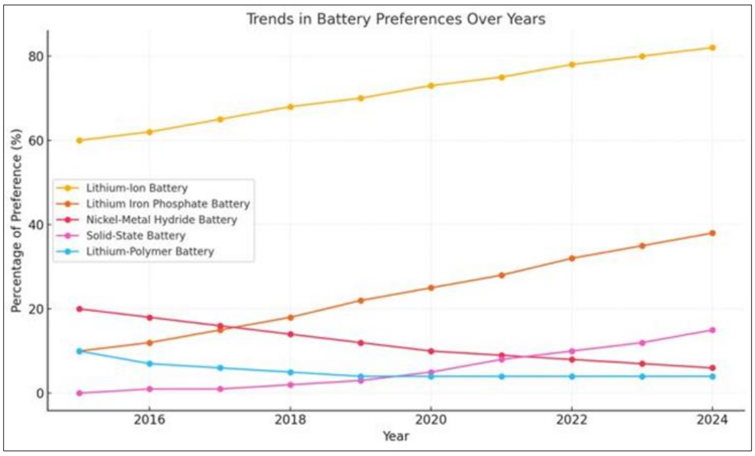


Figure 1 Graphical representation of shifting trends in battery preferences

Battery capacity is the total energy a battery can store. Choosing the right battery chemistry is crucial, as it impacts the capacity of electric vehicles, directly influencing their range and overall performance.

2.1.1. Here's a breakdown of how various chemistries impact capacity

- **Energy Density:** This metric is key to determining how much energy a battery can store relative to its size or weight. Higher energy density allows for more energy storage, thus enhancing the battery's capacity and potentially extending the EV's range. Lithium-Ion batteries stand out for their high energy density, offering significant energy storage in a lightweight package, making them perfect for EVs.
- **Voltage:** Voltage is crucial as it, along with the battery's chemistry, affects the overall energy capacity. Higher voltage means a greater total energy capacity for the battery pack. For instance, Lithium Iron Phosphate (LiFePO4) batteries have a lower voltage compared to standard Li-ion batteries, which translates to lower energy storage but increased safety.
- **Specific Chemistry:** The choice of materials and their chemical composition also dictates a battery's capacity. Due to the unique properties of the materials used, different chemistries result in varying capacities. Lithium iron phosphate (LiFePO4) batteries, for instance, have a lower energy capacity than other lithium-ion variants, a compromise made for enhanced safety and longevity. [2]

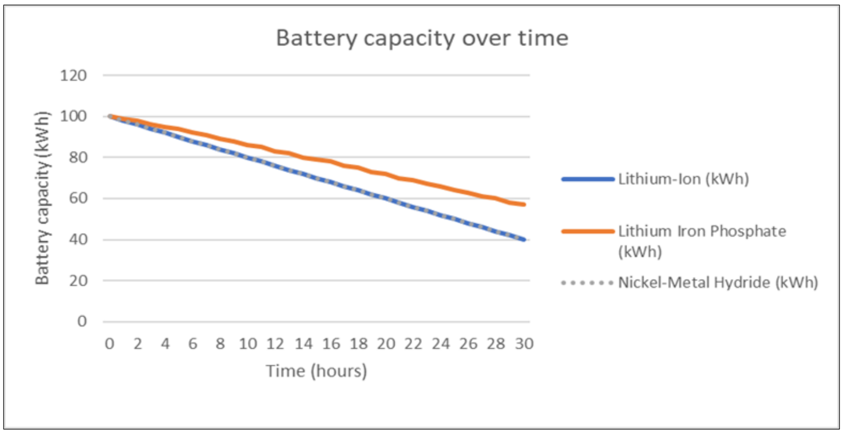


Figure 2 Graphical representation of battery capacity vs time

3. PID controllers and their crucial role in robotics, especially for EVS

3.1. What are PID Controllers?

Precision and control are vital for electric vehicles (EVs). One essential tool for achieving this in EVs is a PID controller. A PID controller, which stands for Proportional-Integral-Derivative, is a control loop mechanism widely used in industrial control systems to maintain the desired output of a process. PID controllers are a fundamental component of the control systems used in EVs, ensuring that the vehicle's performance is finely tuned for efficiency, safety, and user experience.

These controllers are designed to automatically maintain a specific set point (target value) by adjusting the control inputs. In the context of EVs, PID controllers are used to regulate and fine-tune various aspects of the vehicle's operation, such as speed control, torque management, steering assistance, and much more. [3]

3.2. How do PID Controllers Work?

PID controllers work by continuously analysing the difference (error) between a desired set point and the current state of the system. They then apply corrective actions to minimize this error and bring the system back to the desired state. Here's a breakdown of the components:

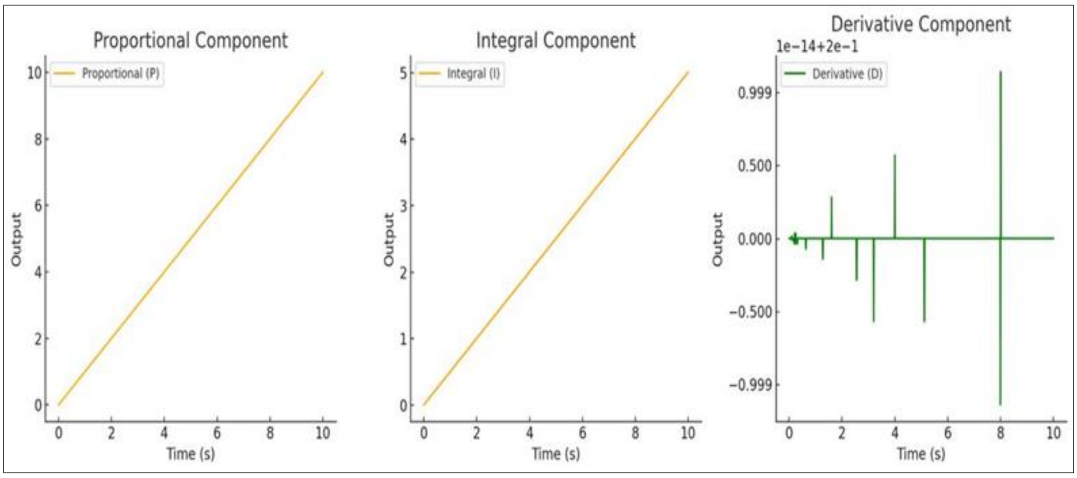
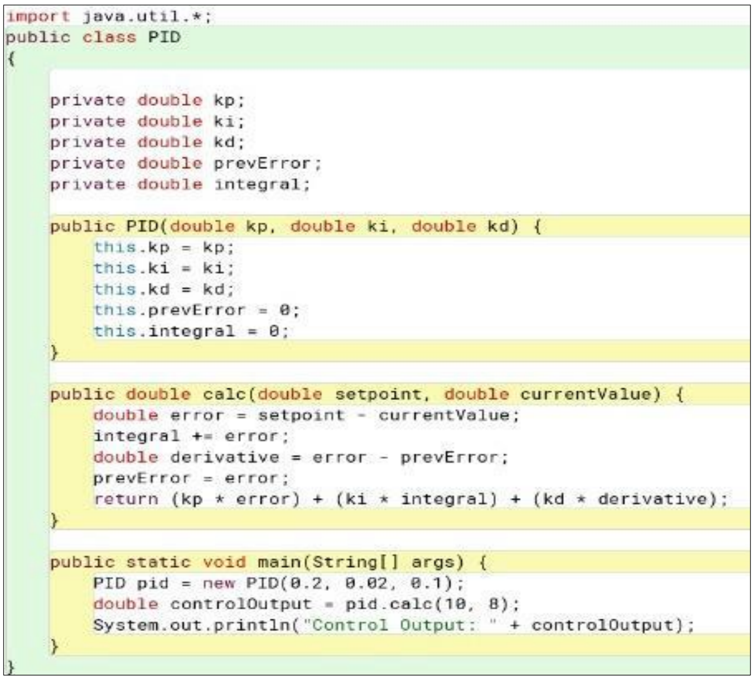


Figure 3 Graphical representation of components of PID

- **Proportional (P):** The proportional term determines the immediate response to the current error. It calculates the proportional response to the current error and applies a correction based on how far off the system is from the set point. In EVs, this could be adjusting motor power to maintain a set speed or torque.
- **Integral (I):** The integral term deals with the accumulation of past errors. It adds up the errors over time and corrects the system to eliminate any residual steady-state error. In an EV, this could help in keeping the vehicle traveling at a consistent speed.
- **Derivative (D):** The derivative term anticipates future behaviour based on the rate of change of the error. It helps in preventing overshoot or instability by slowing down the system's response to rapid changes. For EVs, this could ensure smooth and stable acceleration or deceleration.

In PID tuning, the primary challenge lies in fine-tuning each component (P, I, and D) to achieve the desired performance. This usually involves a trial-and-error process, adjusting values and observing the system's response, and iterating until the controller operates as desired. In the evolving world of EVs, where precise control over vehicle performance is crucial, PID tuning is an ongoing process that contributes to making EVs more efficient, safer, and more enjoyable to drive



```java
import java.util.*;
public class PID
{

    private double kp;
    private double ki;
    private double kd;
    private double prevError;
    private double integral;

    public PID(double kp, double ki, double kd) {
        this.kp = kp;
        this.ki = ki;
        this.kd = kd;
        this.prevError = 0;
        this.integral = 0;
    }

    public double calc(double setpoint, double currentValue) {
        double error = setpoint - currentValue;
        integral += error;
        double derivative = error - prevError;
        prevError = error;
        return (kp * error) + (ki * integral) + (kd * derivative);
    }

    public static void main(String[] args) {
        PID pid = new PID(0.2, 0.02, 0.1);
        double controlOutput = pid.calc(10, 8);
        System.out.println("Control Output: " + controlOutput);
    }
}
```

Figure 4 Java Code for initial response in PID Controllers

In the above example, the PID controller's values are set without any iteration. These values determine the controller's initial response to the error between the desired and current velocities. The expected impact of changes in this scenario would be a certain degree of control over the robot's velocity. However, the exact impact depends on the chosen values of P, I, and D

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4. Applications in EVs

In the realm of EVs, PID controllers are indispensable. They can be found in various vehicle systems and components:

- **Speed control**: PID controllers are used to maintain a consistent vehicle speed by adjusting the power output of the electric motor.
- **Torque management**: In EVs, precise torque control is essential. PID controllers help manage the distribution of torque to the wheels, optimizing traction and handling.
- **Regenerative braking**: When an EV decelerates or brakes, PID controllers can optimize regenerative braking, converting kinetic energy back into electrical energy.
- **Steering assistance**: PID controllers can enhance power steering systems, making steering more responsive and easier at different driving speeds.
- **Battery management**: PID controllers help regulate the charging and discharging of the battery, ensuring its health and safety.
- **Thermal management**: In EVs, maintaining the right operating temperature is crucial. PID controllers help manage the cooling and heating systems for the battery and electric motor.

Figure 5 Electric vehicle displayed in Museum of the Future, Dubai

4.1. PID tuning

PID controller tuning is a critical aspect of making PID-controlled systems work effectively and efficiently, especially in the context of EVs. The importance of tuning lies in the fact that every system and its operating conditions can be unique. As a result, PID controllers need to be finely tuned to ensure optimal performance, responsiveness, and stability.

4.1.1. How does adjusting values affect the behaviour?

- Proportional (P): Adjusting the proportional gain affects the system's immediate response to errors. Increasing P makes the controller more sensitive to errors, causing a quicker response to deviations from the set point. Too high a P value can lead to overshooting or oscillations, while too low a value can result in slow correction.
- Integral (I): The integral term helps eliminate steady-state errors. Adjusting the integral gain alters the controller's capacity to address long-term discrepancies. Raising the integral gain (I) accelerates error correction, but may cause instability and oscillations. Conversely, lower integral gain values slow the elimination of steady-state errors, enhancing stability but slowing correction.
- Derivative (D): The derivative term anticipates and reacts to the rate of change of errors. Changing the derivative gain (D) affects how quickly the controller responds to changes in error. A higher D value provides

a quicker reaction, but it can also make the system more prone to noise and vibration. Reducing D can lead to slower responses and may allow overshooting.

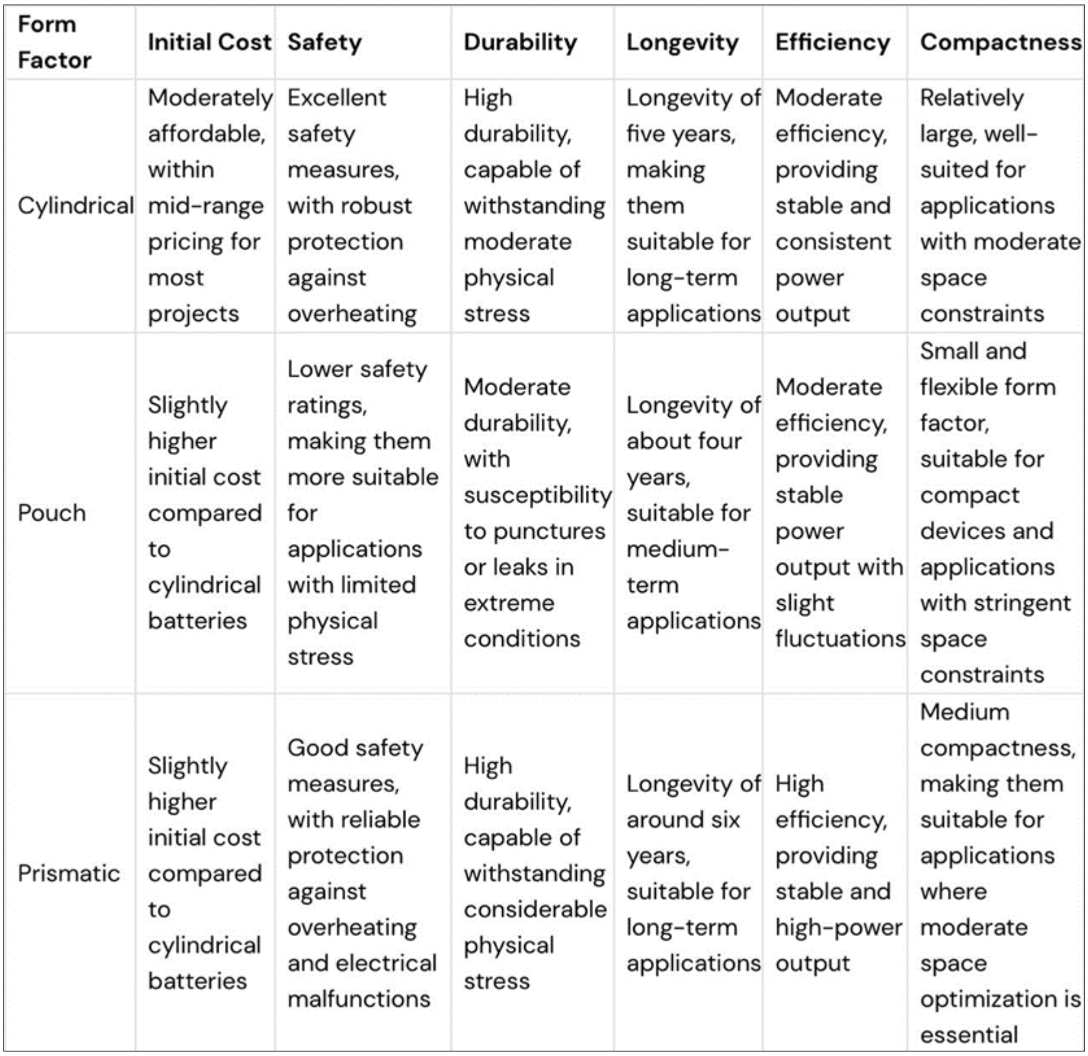
4.2. Design trade-offs

Within the field of engineering, it's important to understand the idea of design trade-offs. Altering a single factor can trigger inverse effects on various critical outcomes. When making a design decision, engineering teams must choose which factors to prioritize and consider compromises between competing parameters.

Consider the example of battery capacity. An increase in capacity may potentially enhance the performance of the mobile robot, yet it could simultaneously escalate costs and compromise aspects such as safety or durability. Conversely, a reduction in battery capacity might lead to cost savings but could potentially curtail the overall performance and longevity of the system. Understanding this interplay is vital to making informed decisions in the pursuit of creating efficient and sustainable EVs.

In the broader context of mobile robotics, design trade-offs can encompass a careful balancing act, with modifications or adjustments potentially having a ripple effect on the overall functionality and viability of the system. It's important to consider how changes will influence the entire system to create a balance between performance, durability, and cost-effectiveness.

4.3. Battery form factor

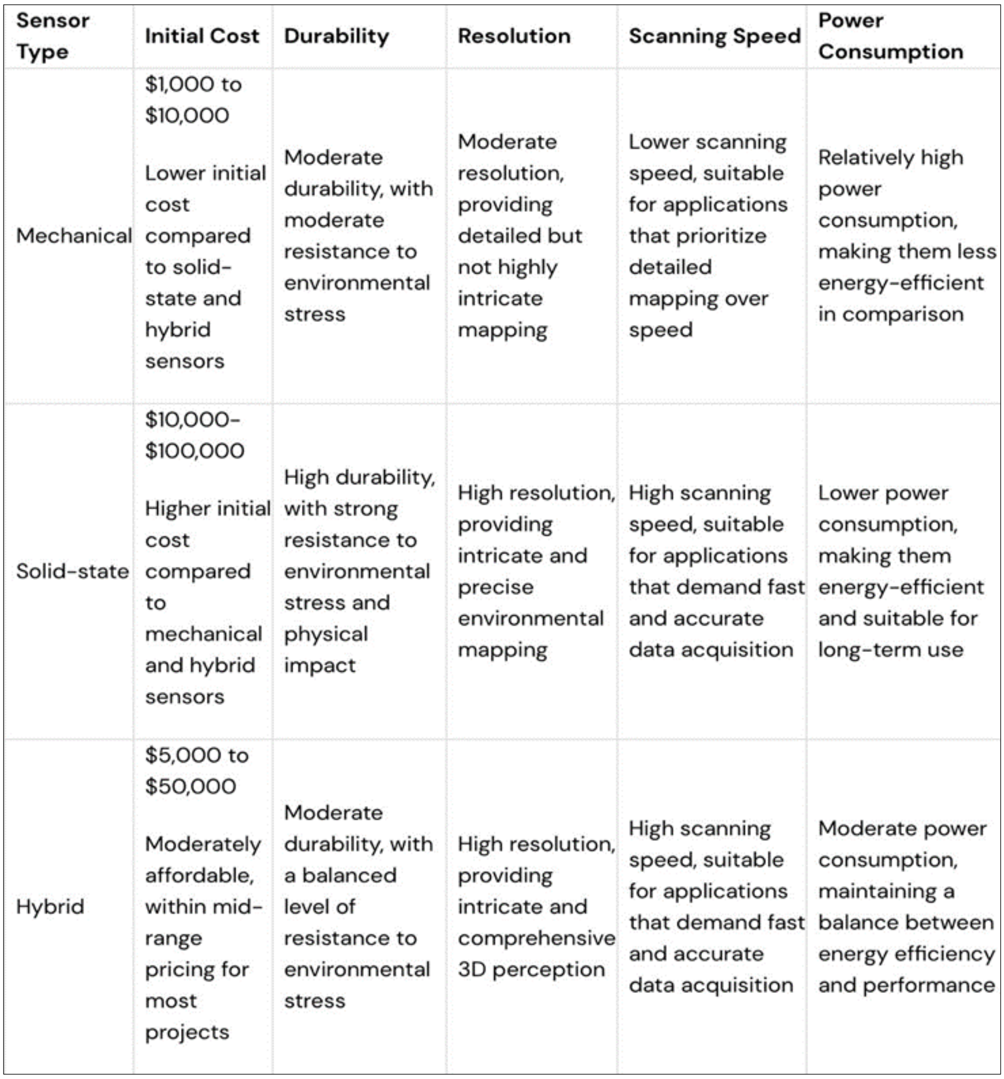


Form Factor	Initial Cost	Safety	Durability	Longevity	Efficiency	Compactness
Cylindrical	Moderately affordable, within mid-range pricing for most projects	Excellent safety measures, with robust protection against overheating	High durability, capable of withstanding moderate physical stress	Longevity of five years, making them suitable for long-term applications	Moderate efficiency, providing stable and consistent power output	Relatively large, well-suited for applications with moderate space constraints
Pouch	Slightly higher initial cost compared to cylindrical batteries	Lower safety ratings, making them more suitable for applications with limited physical stress	Moderate durability, with susceptibility to punctures or leaks in extreme conditions	Longevity of about four years, suitable for medium-term applications	Moderate efficiency, providing stable power output with slight fluctuations	Small and flexible form factor, suitable for compact devices and applications with stringent space constraints
Prismatic	Slightly higher initial cost compared to cylindrical batteries	Good safety measures, with reliable protection against overheating and electrical malfunctions	High durability, capable of withstanding considerable physical stress	Longevity of around six years, suitable for long-term applications	High efficiency, providing stable and high-power output	Medium compactness, making them suitable for applications where moderate space optimization is essential

Figure 6 Table accentuating the differences among cylindrical, pouch and prismatic battery forms

4.4. LiDAR sensors

LiDAR (Light Detection and Ranging) sensors have become indispensable components in the design and functioning of mobile robots, playing a pivotal role in enabling accurate and efficient navigation, mapping, and obstacle detection. LiDAR sensors can provide real-time, high-resolution, three-dimensional (3D) information about the surrounding environment, making them a critical technology for various applications, including autonomous vehicles, drones, and industrial automation [4]



Sensor Type	Initial Cost	Durability	Resolution	Scanning Speed	Power Consumption
Mechanical	$1,000 to $10,000 Lower initial cost compared to solid-state and hybrid sensors	Moderate durability, with moderate resistance to environmental stress	Moderate resolution, providing detailed but not highly intricate mapping	Lower scanning speed, suitable for applications that prioritize detailed mapping over speed	Relatively high power consumption, making them less energy-efficient in comparison
Solid-state	$10,000-$100,000 Higher initial cost compared to mechanical and hybrid sensors	High durability, with strong resistance to environmental stress and physical impact	High resolution, providing intricate and precise environmental mapping	High scanning speed, suitable for applications that demand fast and accurate data acquisition	Lower power consumption, making them energy-efficient and suitable for long-term use
Hybrid	$5,000 to $50,000 Moderately affordable, within mid-range pricing for most projects	Moderate durability, with a balanced level of resistance to environmental stress	High resolution, providing intricate and comprehensive 3D perception	High scanning speed, suitable for applications that demand fast and accurate data acquisition	Moderate power consumption, maintaining a balance between energy efficiency and performance

Figure 7 Table accentuating the differences among Mechanical, Solid-State and hybrid LiDAR Sensors

5. Results and discussions

5.1. Benefits of precise PID tuning

When tuning PID controllers for EVs, you need to consider the specific application, the vehicle's dynamics, and external factors such as road conditions. Precise tuning can have several benefits:

- **Improved Efficiency:** Well-tuned PID controllers enhance power usage, boosting the vehicle's range and efficiency.
- **Smooth Operation:** Correct tuning ensures smoother acceleration and deceleration, enhancing the driving experience.
- **Safety:** Precise tuning is vital for control in various driving conditions, promoting stability and safety.
- **Regenerative Braking:** Efficiently tuned controllers maximize energy capture during regenerative braking, improving energy utilization.

5.2. Review of battery forms

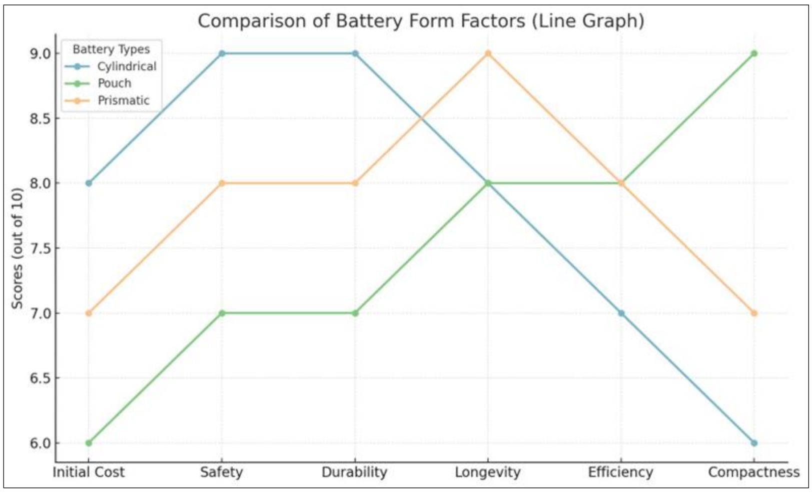


Figure 8 Graph displaying the overall scores of battery form factors

The most suitable battery form factor will vary by project, depending on factors such as cost, safety, longevity, efficiency, and compactness.

- The cylindrical battery form factor appears to be a cost-effective and reliable choice, offering excellent safety and high durability over a five-year lifespan. Its moderate efficiency and relatively larger size suggest suitability for applications where space constraints are not critical and where a balance between cost and performance is essential. [5]
- Pouch batteries, despite their slightly higher initial cost, seem better suited for compact devices due to their small form factor, making them suitable for portable electronics and devices with limited space. However, their comparatively lower safety and durability levels might make them more appropriate for applications that do not entail rigorous physical stress. [6]
- Prismatic batteries, with their slightly higher cost and good safety and durability, along with higher efficiency and medium compactness, are a viable option for applications that prioritize longevity and performance, making them well-suited for electric vehicles and other high-demanding applications where space optimization is moderately important. [7]

5.3. Review of LiDAR sensors

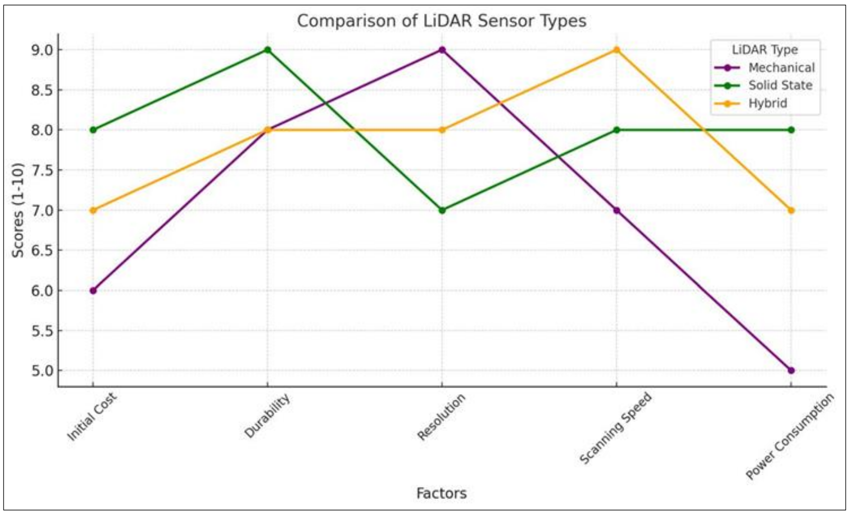


Figure 9 Graph displaying the overall scores of LiDAR Sensor Types

Each type of LiDAR sensor exhibits distinct attributes that render it suitable for different applications.

- Mechanical scanning LiDAR sensors, with their lower initial cost, are ideal for applications that prioritize detailed environmental mapping and navigation over long distances but do not require high-speed scanning. However, their moderate durability and relatively high-power consumption might limit their suitability in dynamic and fast-paced environments.
- Solid-state LiDAR sensors, despite their higher cost, offer enhanced durability, high-speed scanning capabilities, and lower power consumption, making them a preferred choice for applications that demand reliable and precise data acquisition in dynamic and energy-conscious settings. However, they work best for short-range sensing.
- Hybrid LiDAR sensors strike a balance between the two, offering a blend of long-range sensing, high resolution, and fast data acquisition at a moderate cost. They are well-suited for applications that require comprehensive 3D perception while maintaining a reasonable budget.

6. Conclusion

“The machine does not isolate man from the great problems of nature but plunges him more deeply into them.”

- Antoine de Saint-Exupéry, Wind, Sand and Stars

As governments around the world, focus on slowing climate change, electric vehicles are expected to replace gas powered ones altogether. In Norway, 75% of car sales in 2020 were plug-in electric vehicles. And policies such as California’s Zero Emission Vehicle mandate and Europe’s aggressive CO2 emission standards have dramatically slowed investments in gas power vehicles worldwide. Soon electric cars will reclaim their place on the road putting gasoline in our rear-view.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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