Robot Fleet Charging System: Technical Documentation

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Abstract

This document presents a comprehensive overview of the Robot Fleet Charging System, designed to manage a fleet of 5 robots with dynamic battery management requirements. The system implements an intelligent charging algorithm that prioritizes robots with critical battery levels while ensuring continuous operation of the fleet. The algorithm optimizes charging schedules to minimize downtime and maximize battery efficiency under constraints of limited charging infrastructure.

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1 System Overview

The Robot Fleet Charging System manages a fleet of 5 robots, each equipped with a battery that depletes over time during operation and requires periodic charging. The primary goal of the system is to maintain at least 3 robots with a minimum of 20% battery charge at all times, while optimizing the charging schedule according to the following criteria:

- Prioritize charging robots with the lowest battery levels
- Ensure continuous robot operation
- Minimize total charging time
- Maximize battery efficiency

2 System Constraints

The system operates under the following constraints:

- Battery discharge rate: 1% per second
- Battery charging rate: 1.5% per second
- Available charging stations: 2
- Minimum operational robots: 3
- Minimum safe battery level: 20%

These constraints shape the charging optimization strategy and influence the decision-making process in the system.

3 System Architecture

The system consists of two main components:

Robot Class	Compute Class
- robot_id - battery - charging_status - charge_rate()	- threshold_level - threshold_min_switching - priority()

$$\xrightarrow{\text{Battery Data}}$$

$$\xleftarrow{\text{Charging Commands}}$$

Figure 1: System Architecture

3.1 Robot Class

The Robot Class is responsible for maintaining the state of each robot in the fleet. It encapsulates the following attributes:

- `robot_id`: Unique identifier for each robot.
- `battery`: Current battery level (0-100%).
- `charging_status`: Boolean indicating whether the robot is currently charging.

The Robot Class also implements a `charge_rate()` method that simulates battery change per time step:

- If charging: battery increases by 1.5% per second (maximum 100%)
- If not charging: battery decreases by 1% per second

3.2 Compute Class

The Compute Class implements the decision logic for optimizing the charging schedule of the robot fleet. It has the following key attributes:

- `threshold_level`: Critical battery level (default 21%). Robots below this threshold are given highest priority for charging.
- `threshold_min_switching`: Buffer threshold to minimize frequent switching between charging and non-charging states (default 25%).

The primary method of the Compute Class is `priority(fleet_data)`, which determines which robots should be charging based on their battery levels and current charging status.

4 Charging Optimization Strategy

The charging optimization strategy employed by the system follows a sophisticated algorithm designed to balance immediate charging needs with long-term operational stability.

4.1 Robot Scoring Algorithm

Robots are assigned priority scores based on their battery level and charging status:

Algorithm 1 Robot Scoring Algorithm

```
for each robot in fleet do
    if battery ≤ threshold_level then
        score = 0                          ▷ Highest priority, needs urgent charging
    else if battery ≤ threshold_min_switching AND is_charging then
        score = 1                          ▷ Medium priority, avoid switching
    else
        score = 2                          ▷ Lowest priority
    end if
end for
```

4.2 Robot Sorting Logic

After scoring, robots are sorted according to the following criteria:

1. Primary sort: By score (ascending)
2. Secondary sort: By battery level (ascending)

This ensures that robots with the most critical battery levels receive charging priority.

4.3 Charging Assignment Process

The charging assignment process follows these steps:

4.4 Safety Mechanism

To ensure system reliability, a safety check is performed after the initial charging assignments:

This mechanism ensures that at least 3 robots have sufficient battery levels to maintain continuous operation.

Algorithm 2 Charging Assignment Algorithm

```
Sort robots by score and battery level
charging_count = 0
for each robot in sorted_robots do
    if robot.battery == 100% then
        robot.charging_status = False
    else if charging_count ¡ charging_stations then
        robot.charging_status = True
        charging_count += 1
    else
        robot.charging_status = False
    end if
end for
```

Algorithm 3 Safety Check Algorithm

```
safe_robots = count of robots with battery ≥ 20%
if safe_robots ¡ 3 then
    threshold_min_switching = 20%
    Sort robots by battery level (descending)
    Force top 3 robots to charge
end if
```

5 Edge Cases and Handling

The system is designed to handle various edge cases:

Edge Case	**Handling Mechanism**
All charging stations occupied	Only the allowed number of robots (charging_station) will be set to charging, even if more need it.
Fully charged robots	Robots at 100% battery are automatically set to not charging, freeing up stations for others.
Frequent switching	The threshold_min_switching buffer helps avoid toggling a robot's charging state if its battery is just above the critical threshold but still low.
Not enough safe robots	If fewer than 3 robots have battery $\geq 20\%$, the system lowers the switching threshold and forcibly prioritizes the top three robots to charge.

Table 1: Edge Cases and Handling Mechanisms

6 System Output

At each time step, the system provides the following information:

- Number of robots in operational state (battery $\geq 20\%$)
- Each robot's battery level and charging status

Example output format:

```
Time Step: 10
Operational Robots: 4/5
Robot 1: Battery 45% [Charging]
Robot 2: Battery 78% [Not Charging]
Robot 3: Battery 32% [Not Charging]
Robot 4: Battery 15% [Charging]
Robot 5: Battery 56% [Not Charging]
```

7 Performance Metrics

The system's performance can be evaluated using the following metrics:

- **Operational Uptime**: Percentage of time with at least 3 robots above 20% battery
- **Average Fleet Battery Level**: Mean battery level across all robots
- **Charging Efficiency**: Ratio of charging time to operational time
- **Charging Switches**: Number of times robots switch between charging and non-charging states

8 Conclusion

The Robot Fleet Charging System implements a sophisticated charging optimization strategy that ensures continuous robot operation while maximizing battery efficiency. The scoring-based prioritization algorithm, combined with safety mechanisms, guarantees that the system can handle various operational scenarios and edge cases.

The modular architecture, consisting of the Robot Class and Compute Class, provides a clean separation of concerns between robot state management and charging decision logic. This design facilitates future extensions and modifications to the system.

9 Future Enhancements

Potential enhancements to the system include:

- Dynamic adjustment of thresholds based on historical usage patterns
- Predictive charging based on anticipated robot workloads
- Integration with task scheduling to optimize both charging and operational efficiency
- Implementation of machine learning algorithms to further optimize charging strategies