🚲 GreenMoving

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📖 Project Description

Introduction

This project presents the design and implementation of a Self-Adaptive Management System for an urban E-Bike sharing service, orchestrated via Docker it integrates Python-based autonomous agents with InfluxDB for time-series data storage and Grafana for real-time observability. By leveraging a distributed architecture and a MAPE-K (Monitor-Analyze-Plan-Execute-Knowledge), the system autonomously manages e-bikes and smart charging stations.

Managed Resources

Electric Bikes (E-Bikes) The Bikes are the primary mobile assets, each unit is managed as an edge device providing real-time telemetry.

- *State variables*: StateOfCharge, geographic coordinates (lat,lon), lock status, and availability.
- *Management Logic**: System monitors these resources to ensur operational integrity and availability of bikes.

Charging Stations The Stations represent the fixed infrastructure and act as "hubs" for the bikes, each stations has the same number of slots.

- *State Variables*: slot occupancy, slot status, geografic fixed position and total charging power (W).
- *Monitoring Logic*: The system manages station capacity to maintain an equilibrium between supply and demand. Their management is strictly event-driven to ensure maximum energy efficiency and prevent waste, stations are triggered to send state updates only in these cases.
  - Connection
  - Disconnection
  - Bike Fully Charged

Energy Energy is treated as a finite, shared resource constrained by the station's maximum power capacity (P_{tot}).

- *State Variable*: Power delivery per slot (P_{i}) and total station load.
- *Monitoring Logic*: Instead of a static flow, energy is managed as a dynamic priority queue, the system "slices" the available power to maximize the number of fully charged bikes. This process is event-driven and balance is done only on stations updates.

Goals of the System

This system aims to optimize an e-bike sharing ecosystem through real-time bikes monitoring, intelligent power distribution, and event-based stations rebalancing.

Bikes Availability The system ensures that bikes remains operational and within authorized boundaries. It monitors telemetric data to trigger operator alerts under specific failure or risk conditions:

- **Geofencing Violation** A bike is flagged if its coordinates fall outside the predefined operational polygon:

$$\text{if } (lat < LAT_{min} \lor lat > LAT_{max}) \lor (lon < LON_{min} \lor lon > LON_{max})$$

- **Theft Detection** Triggered when significant displacement is detected while the motor is locked and the battery is not charging:

$$\text{if } (\Delta lat > \epsilon \lor \Delta lon > \epsilon) \land \text{locked} \land \neg\text{charging}$$

- **Critical State of Charge** Automated reporting for maintenance when the State of Charge (SoC) falls below the safety threshold:

$$\text{if } SoC < SoC_{threshold} \land \neg\text{charging}$$

Stations Load Balancing To prevent "dead zones," the system maintains station occupancy within a functional buffer, ensuring that users can always find a bike to rent or an empty slot to return one. The occupancy N_{occ} is constrained by the total capacity C:

$$1 \leq N_{occ} \leq (C - 1)$$

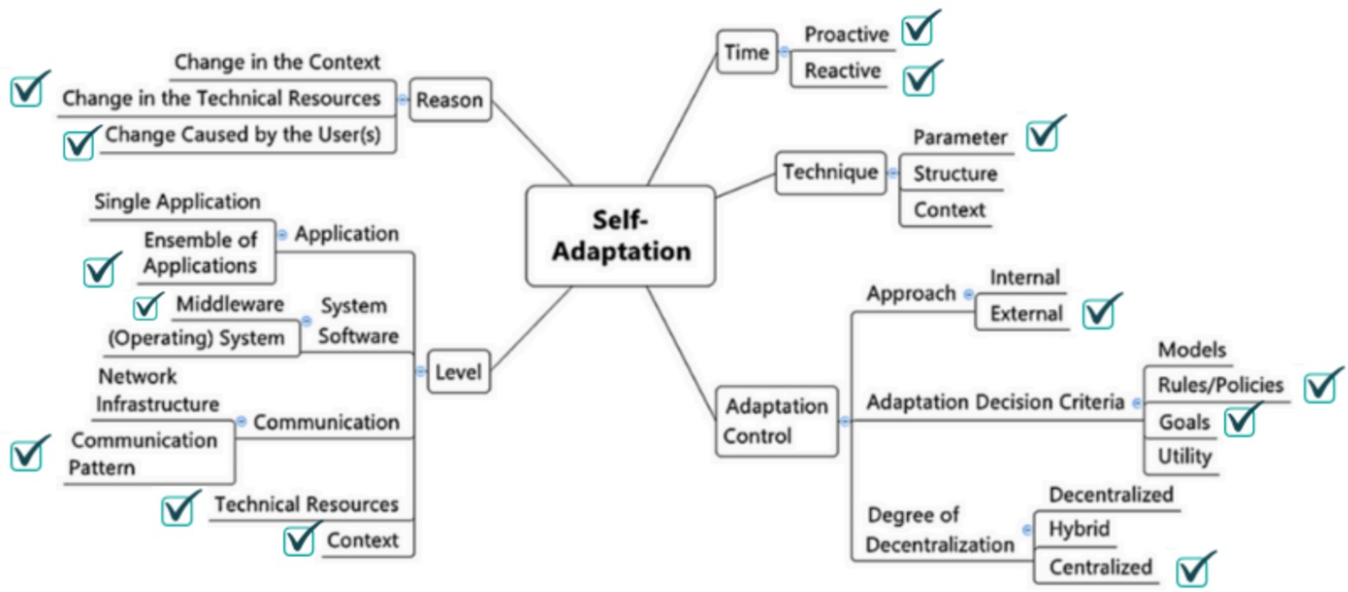
If a station state reaches Full ($N_{occ} = C$) or Empty ($N_{occ} = 0$), the planning module identifies the optimal "Source-Sink" pair and issues a Structural Balance task to the operator dashboard.

Priority Charging & Energy Management To maximize the number of "User-Ready" bikes and minimize energy waste, the system implements a Priority Charging Strategy. Instead of uniform distribution, power P_{tot} is allocated to favor the bike closest to a full charge, accelerating its availability. The power assignment for the priority bike (P_p) and the remaining $n-1$ bikes (P_{other}) is defined as follows:

$$\begin{cases} P_p = 0.6 \cdot P_{tot} \; P_{other} = \frac{0.4 \cdot P_{tot}}{n-1} \end{cases}$$

Logic: Once a bike reaches $SoC = 100\%$, its P is set to 0, and the system dynamically reassigns the priority status to the next candidate in the queue.

Self-Adaptation



The system implements self-adaptive logic to autonomously manage bikes dynamics and energy distribution. Below is the classification of our adaptive strategy:

Time

The system operates on a dual temporal scale:

- *Proactive*: Continuous monitoring of bikes to prevent theft, geofencing violations and maximize availability.
- *Reactive*: Event-driven monitoring for stations, where adaptation is triggered by specific state changes

Technique

The system evaluates real-time *parameters* (SoC, coordinates, occupancy) and adjustable thresholds to trigger corrective actions.

Approach
The approach is *external*, as the adaptation logic is decoupled from the managed resources. The intelligence resides in the Planning and Executor modules, which perceive the state of bikes and stations through the network.

Adaptation Decision Criteria
The system combines two paradigms:

- *Objective-based*: Maintaining station occupancy within the safety interval $1 \le N_{occ} \le (C - 1)$.
- *Rule-based*: Applying specific algorithms (e.g., the 60/40 power split) to optimize energy allocation based on priority queues.

Degree of Centralization
Hybrid because while individual modules (Planning, Analysis, Executor) possess functional autonomy and local logic, they are coordinated through a centralized State Repository (InfluxDB) and orchestrated via Docker Compose.

Reason
Triggering factors:

- *Technical Resource Evolution*: Natural decreasing of battery levels (SoC) during operation.
- *Human Intervention*: Operational changes introduced by the operator and user that books bikes.

Application:
The system is composed of an *ensemble of independent microservices* (containers) that interact asynchronously.

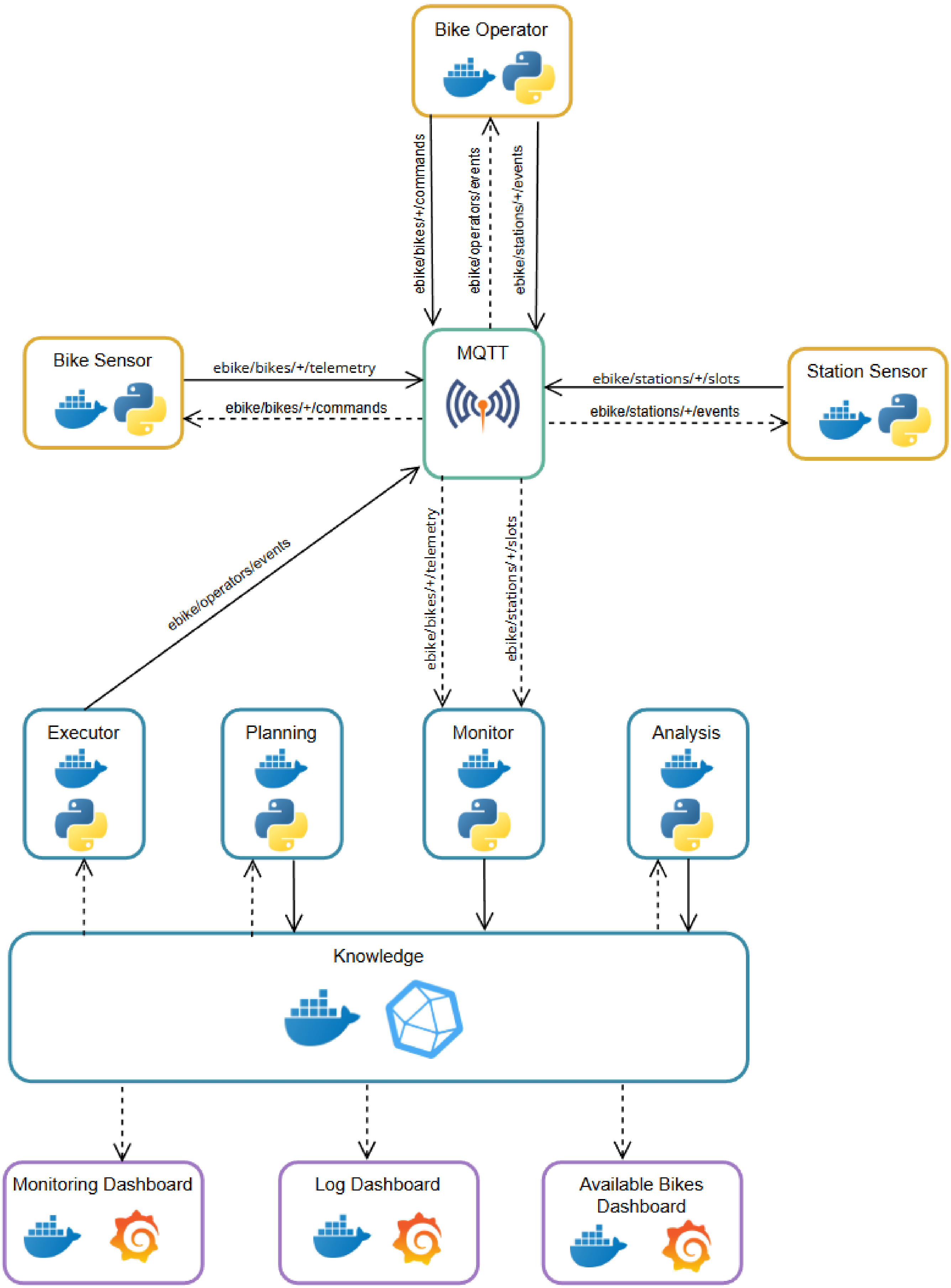
System Software
The software is a *Middleware* and acts as an abstraction layer between the physical/simulated infrastructure (sensors/actuators) and the high-level decision-making logic.

Communication
System relies on specific *communication patterns*:

- *MQTT*: For low-latency, asynchronous message brokering between edge resources and the monitor.
- *InfluxDB*: For time-series data persistence and historical state analysis.

Context & Technical Resources
The system monitors both the *context* (station full or empty) and the *technical resources* (level of battery)

System Architecture



Sensors & Actuators

The system interacts with the environment through three main entities using the MQTT protocol.

- *Bike Sensor*: Act as sensors (telemetry) and actuators (locking/availability).
  - `ebike/bikes/+/telemetry`: publisher
  - `ebike/bikes/+/commands`: subscriber
- *Station Sensor*: Manage physical charging and energy flow.
  - `ebike/stations/+/slots`: publisher
  - `ebike/stations/+/request`: subscriber
- *Bike Operator*: A specialized agent that performs physical tasks (moving bikes, manual charging) to simulate system dynamics.
  - `ebike/operators/events` subscriber

Monitor

he Monitor module acts as a bridge between the MQTT broker and the Time-Series Database (InfluxDB). It subscribes to telemetry and slot topics, persisting raw data into two primary measurements:

`bikes`

bike_id	battery	motor_locked	is_charging	is_available	lat	lon
B1	89	True	False	True	42.3455	13.3554

`station`

station_id	slot1	slot1_rate	slot2	slot2_rate	slot3	slot3_rate	slot4	slot4_rate	slot5	slot5_rate
S1	B1	20	empty	0	empty	0	empty	0	empty	0

Analysis

The Analysis module queries the raw data and applies threshold-based logic to detect critical states, generating Events that require adaptation:

`structural_balance`: Monitors station occupancy

station_id	event_type
S1	FULL

`energy_waste`: Detects changes in station connectivity to trigger power re-balancing.

station_id	event_type
S1	UPDATED

`bike_recharging`: Identifies units with $SoC < Threshold$

bike_id	event
B1	LOW_BATTERY

`bike_availability`: Calculates real-time availability and time-to-readiness for the user dashboard.

bike_id	event	minutes
B1	AVAILABLE	5

`event`: A centralized logging measurement for human-readable audit trails.

description
Theft alarm for Bike B1

Planning

The Planning module retrieves active events and calculates the optimal corrective actions using the system's optimization rules:

`plan_structural_balance`: Selects the best "Source-Sink" pair to move a bike from a full station to an empty one and viceversa.

bike_id	station_id_start	slot_start	station_id_end	slot_end
B1	S1	slot5	S2	slot1

`plan_recharging`: Identifies the optimal available slot for a low-battery bike and creates a reservation.

bike_id	station_id	slot
B1	S1	slot3

`plan_energy_waste` Implements the Priority Charging Logic (60/40 split), calculating the precise charging rate for each docked bike.

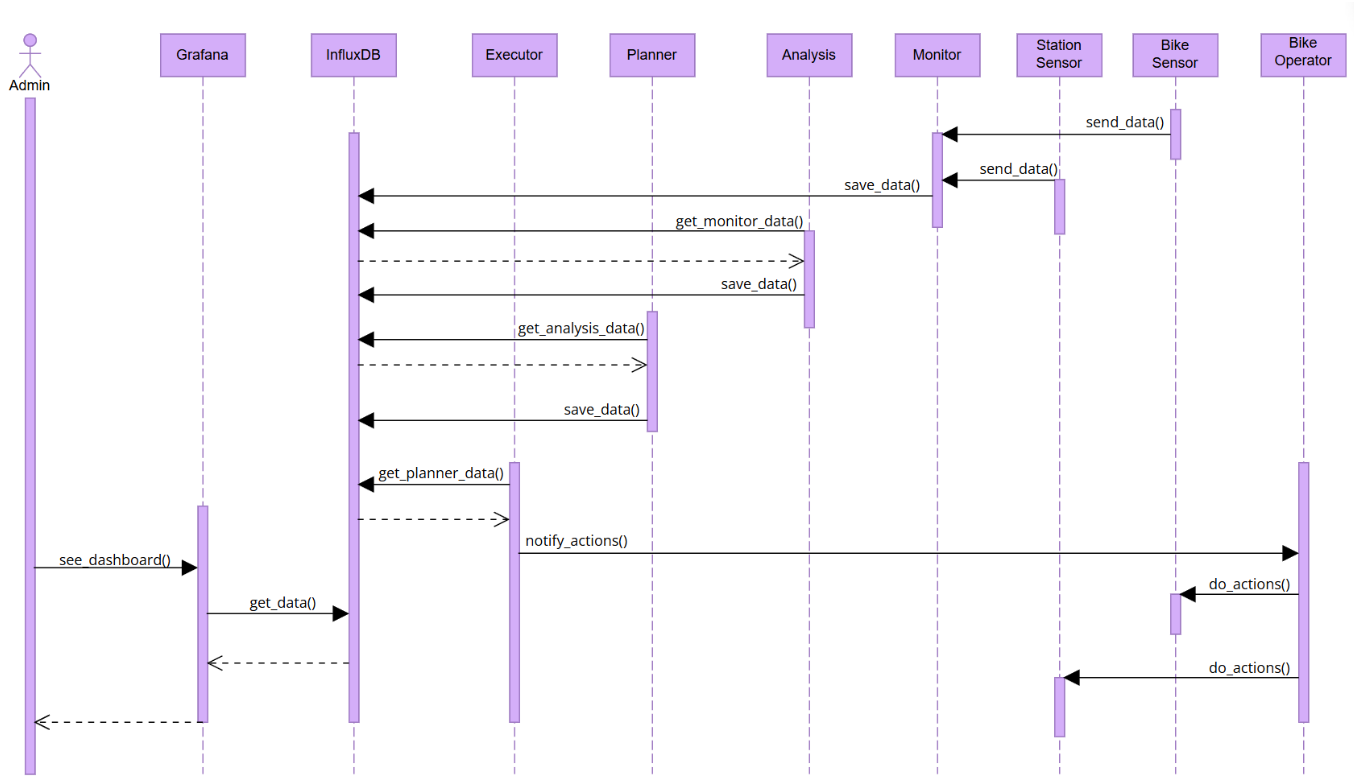
station_id	slot	rate	bike_id
S1	slot2	10	B1

Executor

The Executor translates the high-level plans into actionable commands, dividing them into two execution paths:

- *Direct Automated Control*: It sends BALANCE requests directly to the Station topic (ebike/stations/+/request) to adjust charging rates in real-time.
- *Human-in-the-loop Simulation*: Since structural rebalancing and charging connections require physical movement, the Executor dispatches MOVE or CHARGE tasks to the Bike Operator via the operator topic.

Sequence Diagram



🚀 Installation

Prerequisites

- Windows 10/11
- Docker Desktop 4.58.0
- Python 3.13.9 (for local development and testing only)

🏗 Project Structure

```
📁 nome_progetto
├ 📁 src/        # source code
├ 📁 docs/       # documentation
├ 📁 tests/      # Test unitari
├ 📄 README.md   # Documentazione principale
```

Installation Steps

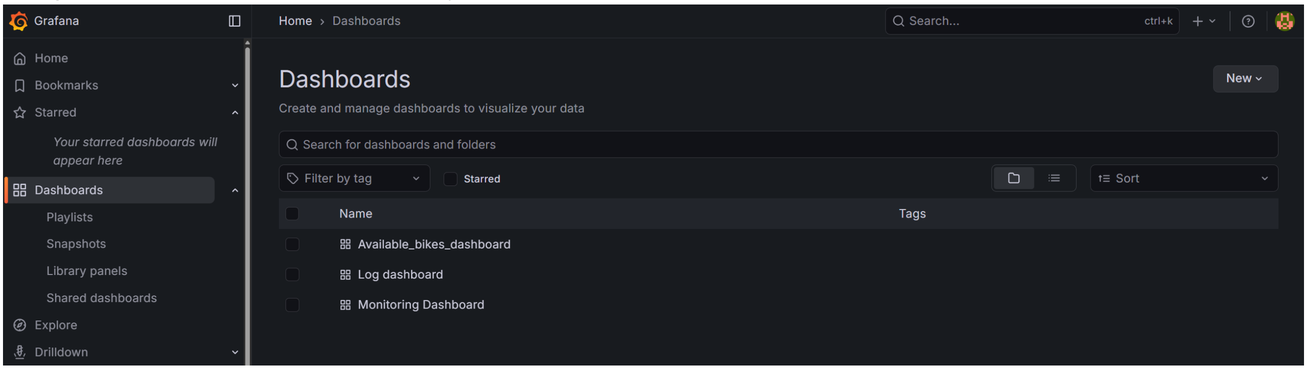
1. Clone the repo

```
git clone https://github.com/m4rylu/SE4AS_GreenMoving
cd SE4AS_GreenMoving/src
```

2. Build and launch the system

```
docker-compose up --build -d
```

3. Navigate to http://localhost:3000/ where you will have access to all dashboards



4. Select one of them for retrieving information about monitoring, availability and events.

Monitoring Dashboard	Availability Dashboard	Log Dashboard