Mobile Robot Navigation

Navigation is essential for robots to move safely and efficiently in their environment. Successful navigation involves four key steps:

1. **Perception** – The robot collects and interprets sensor data.
2. **Localization** – The robot determines where it is in the environment.
3. **Cognition** – The robot decides what action to take.
4. **Motion Control** – The robot moves according to its planned path.

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1. Reactive Navigation (Quick Decision-Making)

- Used in unpredictable environments where pre-planned paths might not work.
- The robot continuously detects obstacles and reacts instantly.
- Sensors like LIDAR, ultrasonic, and infrared help avoid collisions.
- Common in **autonomous vehicles and mobile robots**.

👉 **Example:** A robot in a factory detects an obstacle and changes direction to avoid it.

Localization in Mobile Robot Navigation

Localization helps a robot determine and update its position in a given environment.

Challenges in Robot Localization

1. **Position Tracking (Dead Reckoning)**
    - The robot estimates its position based on previous locations.
    - Uses sensors like wheel encoders and IMU.
    - Errors build up over time, leading to drift.
2. **Global Localization**
    - The robot has no initial position data and must determine where it is.
    - Uses sensors like LIDAR, cameras, and GPS to match a map.
    - Harder than position tracking because the robot starts without any reference.
3. **Kidnapped Robot Problem**
    - The robot is moved unexpectedly and does not know its new location.

- If not detected, it leads to navigation errors.
- Requires error detection to reset and re-localize.

Localization Process

Two key steps help a robot maintain an accurate position:

1. **Prediction (Position Estimation)**
    - Uses movement sensors (IMU, wheel encoders) to guess the new position.
    - Errors increase over time.
2. **Perception (Correction)**
    - Uses external sensors (LIDAR, GPS, cameras) to correct position errors.
    - Compares sensor data with a map to improve accuracy.

Challenges in Localization

1. **Sensor Limitations**
    - **GPS:** Good outdoors but weak indoors.
    - **Other sensors (LIDAR, cameras, ultrasonic, infrared):**
        - Noisy readings (errors in measurement).
        - Limited range and affected by environmental factors.
2. **Unpredictable Real-World Events**
    - Slipping, collisions, or external disturbances affect localization.
    - The robot must detect and recover from errors.
3. **Changing Environments**
    - Maps are static, but the real world changes (moving objects, new obstacles).
    - The robot needs to update its map dynamically.

Solutions to Improve Localization

1. **Sensor Fusion**
    - Combines multiple sensors (GPS, LIDAR, cameras, IMU) for better accuracy.

- Uses techniques like **Kalman Filters** or **Particle Filters**.

2. **Adaptive Localization Algorithms**
    - Updates maps when environments change.
    - Uses **Simultaneous Localization and Mapping (SLAM)** to map and localize at the same time.
3. **Error Detection & Recovery**
    - Detects when the robot's position is incorrect and resets localization.

Challenges of Localization: Noise & Errors

1. **Sensor Noise**
    - Sensors do not always give accurate readings due to environmental factors.
    - Example: A camera’s color detection changes with lighting, affecting accuracy.
2. **Sensor Aliasing**
    - Some sensors cannot differentiate between objects well.
    - Solution: Use multiple sensors (e.g., combining cameras with LIDAR).
3. **Effector Noise (Motion Errors)**
    - The robot’s movement is not always perfect, leading to position errors.
    - **Odometry (wheel sensors) and dead reckoning (motion tracking)** accumulate errors over time.
4. **Types of Odometry Errors**

    Errors might be deterministic (systematic); thus, they can be eliminated by proper calibration of the system.

    Nondeterministic (random) errors that remain, leading to uncertainties in position estimation over time.

    From a geometric point of view, one can classify the errors into three types:

    - **Range Error:** Mistakes in distance traveled.
    - **Turn Error:** Mistakes in turning angles.
    - **Drift Error:** Small differences in wheel movement causing angular errors.

Reducing Errors

- **Calibration:** Fix systematic errors (e.g., wheel alignment).
- **External Corrections:** Use external sensors to update position periodically.
