Ajdar Civan Kırmızıgül

# Çukurova University
Computer Engineering

## GoalPilot
Goal-Biased Autonomous Navigation
in an Unknown Environment

# Table of Contents

# Table of Contents

## Project Goal

### Problem statement

- Build a simulated mobile robot that can navigate autonomously in an unknown environment.
- The robot must not use a pre-saved map and must still explore, avoid obstacles, and plan paths to reach a target.

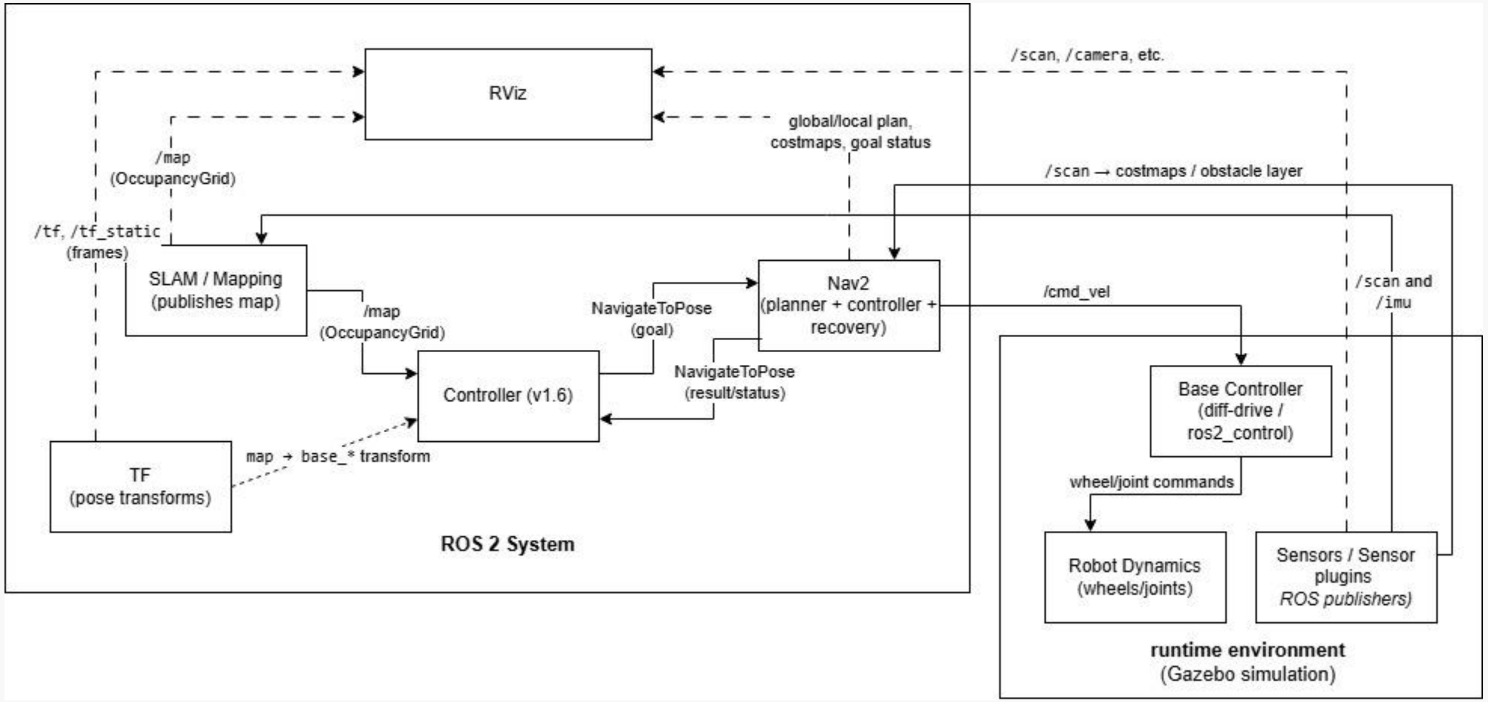
### Objective

- Develop the system in ROS + Gazebo and visualize/debug in RViz.
- Apply ROS fundamentals (nodes, topics, services, parameters, launch files) to build a working navigation pipeline.
- Deliver a clear demonstration and explain the design, challenges, and results.

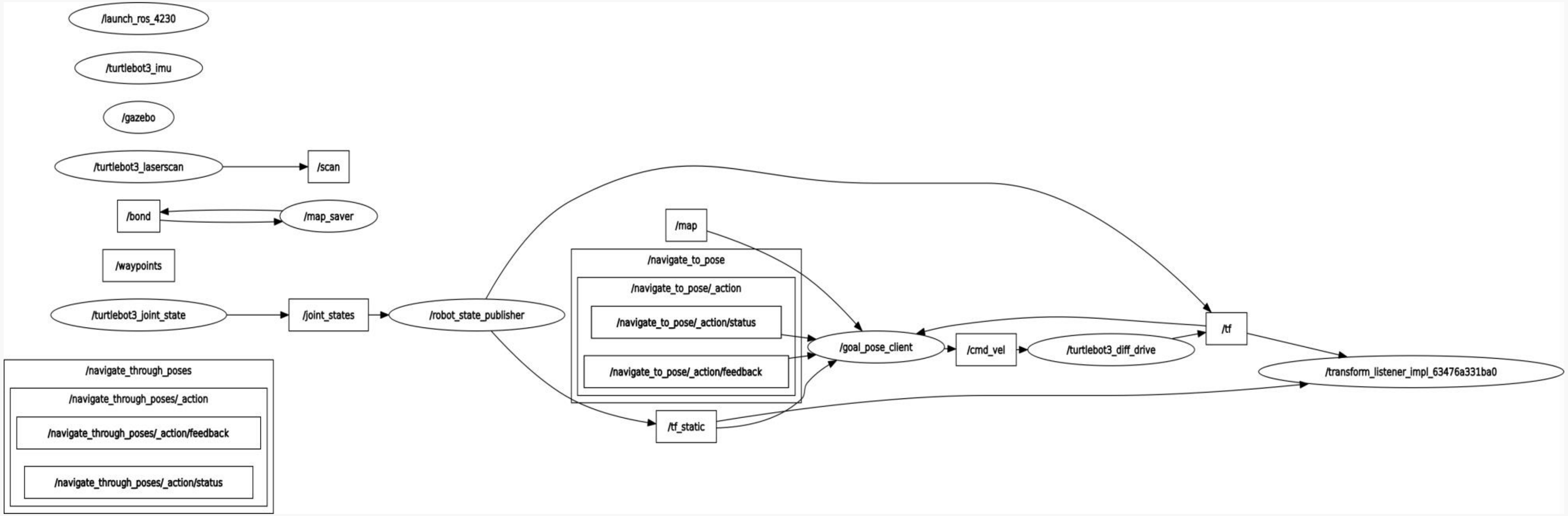
## Problem Constraints

- **Unknown environment:** the map is not available at the start
- **No pre-saved map allowed:** mapping must be built online during the run
- Must support **exploration + navigation** in the same system
- Must handle **path planning** while moving toward the target
- Must perform **obstacle avoidance** to stay collision-free
- Implemented and tested in **ROS + Gazebo**, visualized in **RViz**

# System Architecture


RViz
/scan, /camera, etc.
global/local plan, costmaps, goal status
/map (OccupancyGrid)
/tf, /tf_static (frames)
/scan → costmaps / obstacle layer
SLAM / Mapping (publishes map)
/map (OccupancyGrid)
NavigateToPose (goal)
Nav2 (planner + controller + recovery)
/cmd_vel
/scan and /imu
Controller (v1.6)
NavigateToPose (result/status)
Base Controller (diff-drive / ros2_control)
TF (pose transforms)
map → base_* transform
wheel/joint commands
ROS 2 System
Robot Dynamics (wheels/joints)
Sensors / Sensor plugins ROS publishers)
runtime environment (Gazebo simulation)

# ROS Nodes & Dataflow



# Algorithm Loop

1) **Wait for inputs:** /map available + TF map → base_* pose
2) **Target selection (each attempt):**
   - If main goal is known + safe → go directly
   - Else choose a subgoal near the goal (sample rings around goal, filter safe cells)
   - Score candidates: closer to goal + higher clearance + frontier bonus
3) **Execute:** send Nav2 NavigateToPose (yaw strategy: subgoals face goal; final goal keeps yaw to reduce spinning)

## Algorithm Loop

4) **Monitor:** wait for SUCCEEDED / ABORTED, with a hard timeout (cancel if stalled)

5) **Replan:**

- If SUCCEEDED at main goal → done
- If SUCCEEDED at subgoal → enable FINAL MODE, try main goal again
- If ABORTED/timeout → optional small backup+rotate if no progress, expand search radius, retry up to max attempts

## Challenges & Solutions

### Iteration Timeline

**v1.0 – Reactive exploration was unreliable**

- **Challenge:** Random wandering often oscillated near walls and revisited the same space; goal stayed unknown.
- **Solution:** Baseline “explore until goal cell is known, then send Nav2 goal” (worked sometimes, not consistent).

**v1.1 – Robot gets stuck / no progress**

- **Challenge:** Robot could appear moving but made no real progress (local traps).
- **Solution:** Added odometry-based stuck detection + a small exploration state machine (forward / rotate / escape trigger).

# Challenges & Solutions

## Iteration Timeline

**v1.2 - v1.3 – Escaping tight spaces and local minima**

- **Challenge:** Simple rotate/forward behaviors still failed in corners and narrow passages.
- **Solution:** Implemented structured escape maneuvers (backup + angle sweep / probe) and early stop to re-check the goal periodically.

**v1.4 – Major redesign: goal-biased exploration**

- **Challenge:** “Explore first, then navigate” is inefficient and not goal-directed.
- **Solution:** Switched to map-driven intermediate targets (subgoals) near the goal:
  - world↔map utilities, safety dilation, frontier-like candidates,
  - TF-based pose in the map frame for structured replanning.

# Challenges & Solutions

## Iteration Timeline

**v1.5 – Better subgoals + Nav2 edge-case handling**

- **Challenge:** Some subgoals were technically valid but low quality; Nav2 behavior could stall or end awkwardly.
- **Solution:** Added candidate scoring (goal distance + clearance + frontier bonus), plus FINAL MODE to attempt the true goal when appropriate, and tighter Nav2 monitoring.

**v1.6 (Final) – Stabilize and simplify**

- **Challenge:** End-game oscillation and overly complex heuristics reduced consistency.
- **Solution:** Kept subgoal + scoring, but stabilized execution:
  - hard timeout + cancel if stalled,
  - simplified recovery (backup+rotate only when no movement),
  - yaw strategy to reduce spinning near the end.

## Results

### Validated Capabilities

- **Goal-biased navigation without a pre-saved map:** if the main goal is not safe/known, the robot selects map-based subgoals near the goal and keeps replanning.
- **Clear success condition:** run finishes only when Nav2 returns SUCCEEDED at the main goal.
- **More stable execution:** each Nav2 goal has a hard timeout; stalled goals are canceled and replanned.
- **Reduced end-game spinning:** subgoals face the main goal, but the final goal keeps current yaw by default.
- **Simple recovery only when needed:** if Nav2 aborts and the robot barely moved, apply backup + rotate, then retry.

## Results

### Key parameters

- **Safety / sampling:** SAFETY_CELLS=4, SEARCH_MAX_RADIUS=0.9 m, SEARCH_STEP=0.05 m
- **Scoring weights:** W_GOAL=1.0, W_CLEAR=1.8, W_FRONTIER=0.35, CLEARANCE_CAP_M=2.0
- **Robustness limits:** NAV2_GOAL_TIMEOUT_SEC=90 s, MAX_REPLANS=30
- **Yaw / recovery toggles:** SEND_FINAL_YAW_WITH_NAV2=False, ENABLE_SIMPLE_RECOVERY=True
- **Recovery motion:** BACKUP_DIST=0.20 m, ROTATE_DEG=25°