Lecture 16, Nov 2, 2023

Real-Time Obstacle Avoidance

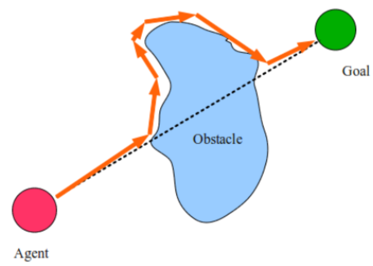

Figure 1: Bug algorithm.

- The bug algorithm is the simplest obstacle avoidance algorithm; the robot just follows the perimeter of the obstacle and resumes on the desired path when possible
  - This assumes we can trace the edge of the obstacle, which is not realistic for non-holonomic robots
  - Only the most recent sensor reading is used so this is very susceptible to noise
- The bubble-band technique creates a bubble of free space around the robot; the bubble is elastic and sensor and obstacle uncertainty can be accounted for by adjusting the bubble
  - This requires a map
- The vector field histogram (VFH) algorithm builds a local probabilistic occupancy grid around the robot, and transforms it into polar coordinates; valleys where obstacle probability is low are identified as potential paths
  - The selected path is usually based on minimization of a path function
  - $G \sim c_1 \Delta\phi_k + c_2 \Delta\theta_k + c_3 \Delta\theta_{k-1}$
  - $\Delta\phi_k$ is the difference between the candidate path direction and the robot's preplanned desired path
  - $\Delta\theta_k$ is the difference in the candidate path direction and current direction
  - $\Delta\theta_k$ is the difference in the candidate path direction and previous directions
- The dynamic window approach (DWA) creates a search space for motion in terms of (linear and angular) velocities
  - Constraints and obstacles are represented as unfeasible areas in the velocity space
  - This allows us to take into account nonholonomic constraints
  - Like vector field histogram but in velocity space, whereas vector field histogram was about position
  - The path is approximated as a circular arc at each instant in time; each arc is defined by (v_k, ω_k) and limited to admissible velocities (i.e. velocities that allow us to stop in time)
  - Maximize a cost function, e.g. $G \sim c_1 \dfrac{1}{\Delta\phi_k} + c_2 \Delta d_k + c_3 \|v_k, \omega_k\|$ where $\Delta\phi$ is the change fro m the desired path, Δd_k is the distance to obstacles

Navigation and Control Architecture

- How do we design a navigation architecture?
- There are two ways to break down the architecture:
  - Temporal decomposition: distinguish processes having different levels of real-time demands
    * We can consider a hierarchy of processes that require increasing levels of temporal constraints
    * Offline planning (no temporal constraints), strategic decision making (few temporal constraints), quasi-real-time decision making (immediate action), real-time decision making (servo-level control)
  - Control decomposition: distinguish processes having different roles and running at different frequencies
    * Consider a hierarchy of processes that require increasing frequencies

    * Path planner, obstacle avoidance, emergency stop, low-level PID control
- There are 2 major paradigms:
  - Deliberative: traditional sense-plan-act; top-down approach
    * Some algorithm is used to determine the action to take
  - Reactive: parallelized planning with multiple concurrent, independent behaviours; most important action takes precedent; bottom-up approach
    * Action with the highest hierarchy gets executed
    * Subsumption architecture: higher levels of behaviour subsume lower levels

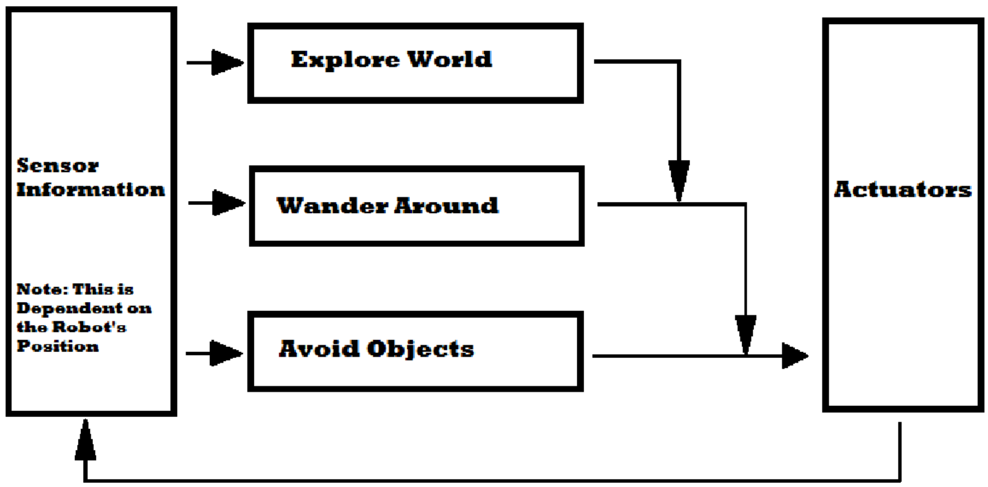

Figure 2: Subsumption architecture is a type of reactive paradigm.

- Subsumption philosophy has 4 principles:
  - Situatedness: “the world is its own best model”
    * The robot interacts with the environment directly without a world model
  - Embodiment: “the world grounds regress”
    * Using real physical systems, not theoretical or simulation models
    * Behaviours are grounded in the real world
  - Intelligence: “intelligence is determined by the dynamics of interaction with the world”
    * Perceptual and mobility skills are necessary for intelligence
  - Emergence: “intelligence is in the eye of the observer”
    * Individual low-level behaviors are not intelligent, but intelligence emerges from interaction of behaviours with each other and the world