Infrastructure to support robots: a practical, scalable model for comparative evaluation of design choices

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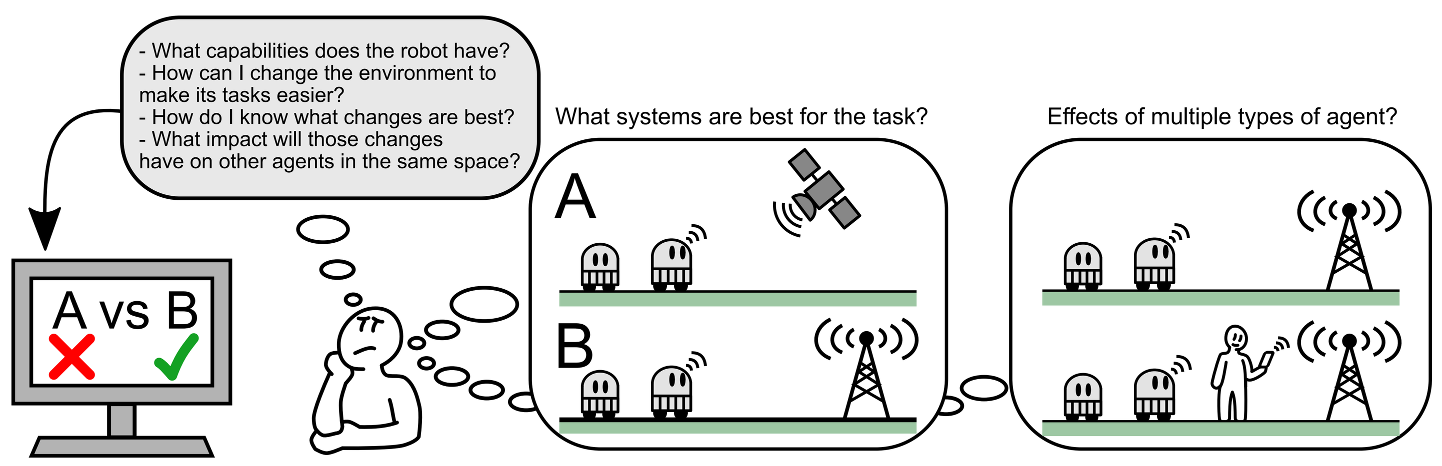
Overview

- Highly structured environments can make robots more effective.
- External elements are often not considered as part of the design process for the robot itself.
- Such elements can encode or enhance perception, alter the effects or costs of actuation, or provide constraints.
- These environmental elements can also be shared, scaled elastically, and have distributed installation/operating costs.
- We introduce a basic but flexible mathematical model for *infrastructure in support of robots*.
- This framework allows for:
  - the rational evaluation and comparison of proposed additions and changes,
  - assessment of the number of agents needed for recouping costs and economical investment,
  - evaluation and categorization of the effect of infrastructure upon agents.

Idea



Features of Infrastructure

We use the following features to differentiate *infrastructure for robots* from cases where there exists some structure in the environment:

1. **Group Utilization:** Available to multiple agents.
2. **Elastic Scaling:** Potential for future extension.
3. **Reusable:** Can be used multiple times.
4. **Cost Distribution:** Costs are distributed over the users.
5. **Fairness:** It should not harm any one group unduly.
6. **Impacts Agent Behavior:** *Measurable impact* on agent behavior.

Categorizing Infrastructure

Mode of Effect: The way in which infrastructure seeks to influence agent behavior:

- **Perception** seeks to change what the agent senses in the environment to elicit a different behavior.
- **Actuation** seeks to change the outcomes of actions taken by agents, without changing what actions are chosen.

Observable Result: The observable outcomes of infrastructure on the agent:

- **Precision** indicates that the infrastructure changes the probabilities of certain information being sensed or a particular state being achieved.
- **Efficiency** indicates that the infrastructure changes the cost of a robot's movement through the world.

Examples

Infrastructure that affects perception

Improved precision in sensing through changes in the environment

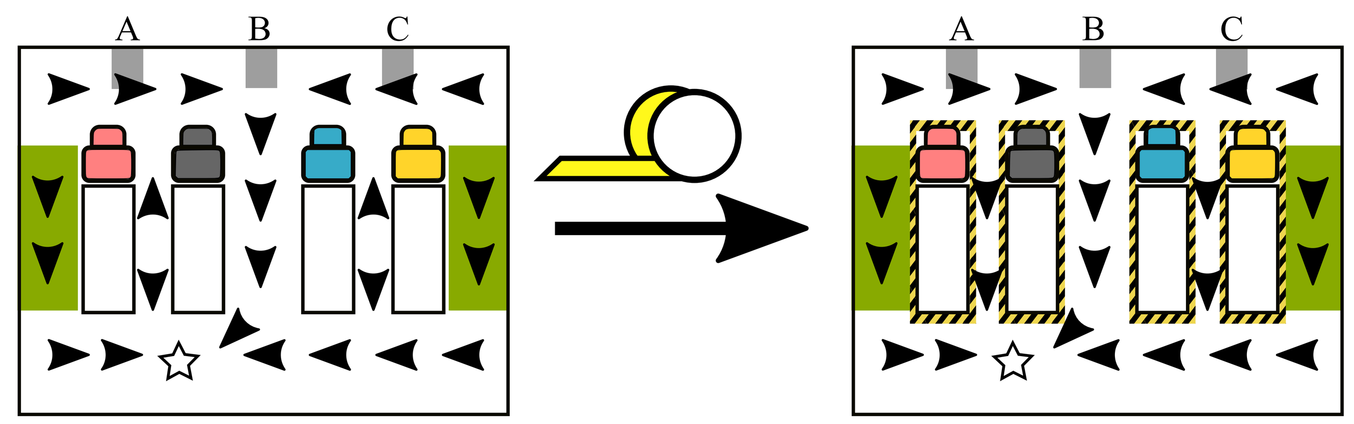


Figure 1: The Warehouse.

Robots in a warehouse avoid passing through certain areas near trucks due to poor sensing of obstacles and high penalties if a collision occurs. Application of high-visibility tape improves sensing precision, changing agent flow. **Left:** Uncertainty in sensing causes agents to take a longer path to avoid obstacles. **Right:** High-visibility markings allow agents to pass between trucks safely.

Improved efficiency through modifying what is sensed

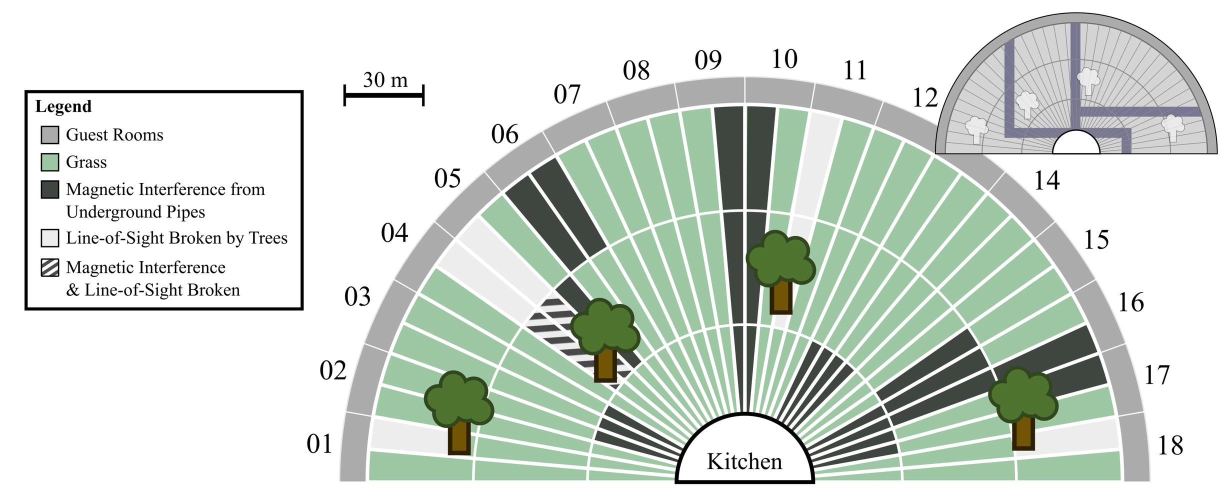


Figure 2: The Hotel Atrium.

A hotel uses a robot to deliver room service from a kitchen (center) to various rooms surrounding an indoor atrium. The robots currently use a compass to determine their position, which receives interference from underground pipes (see inset). A system with a central beacon has been proposed as an alternative, but introduces new areas where interference occurs from loss of line-of-sight. The proposed infrastructure can be compared against the existing compass system to determine potential performance improvements.

Infrastructure that affects actuation

Improved precision in actuation outcomes through changes in the environment

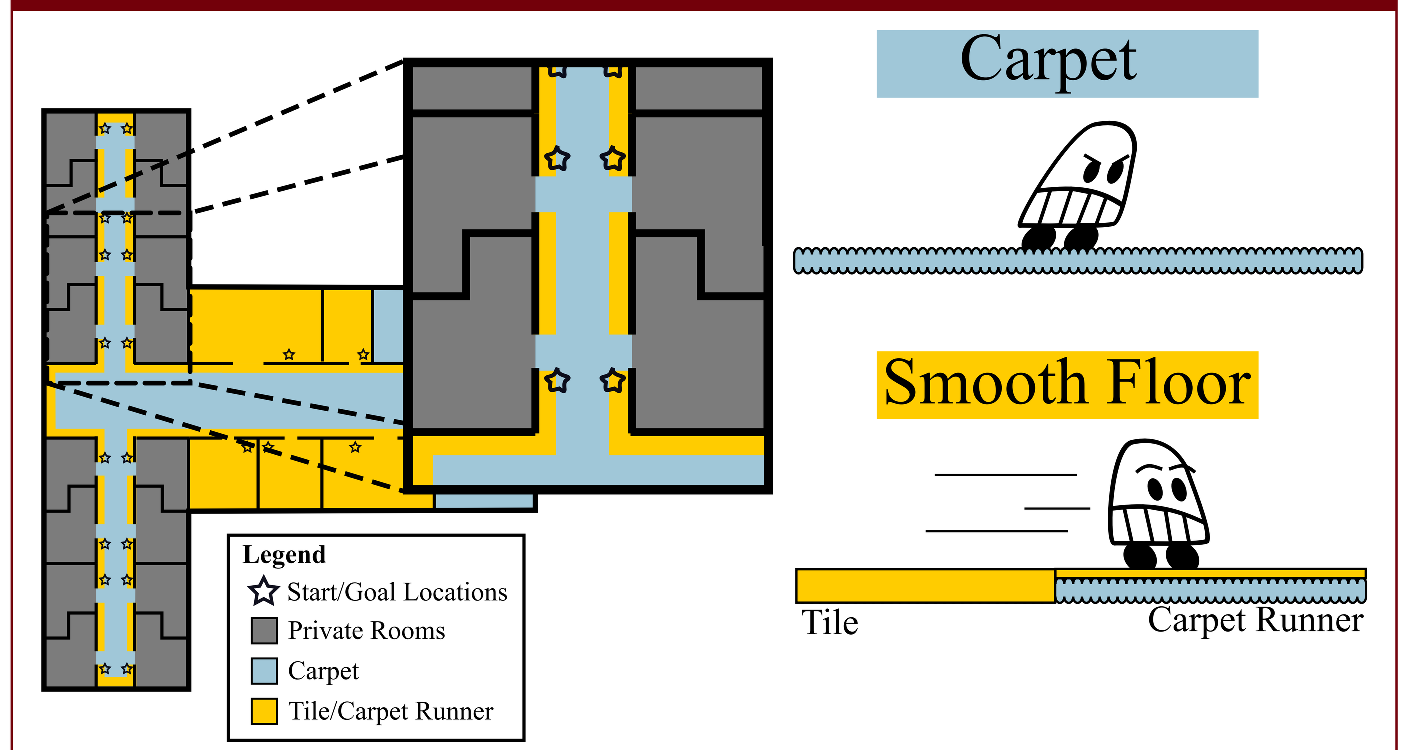


Figure 3: The Long-term Care Facility.

Low-pile carpet such as berber carpet is common within residental facilities to reduce dust and noise. Compared to tile floor, carpet:

- Reduces the accuracy of rotation and other movements,
- Requires additional energy for the robot to travel over, and
- Accelerates carpet wear.

Adhesive carpet runners create surfaces that allow robots to move over carpet with the same efficiency and accuracy as it does over tile. However, runners present a trip hazard for residents, and cannot cross over doorways or hallways. Given these restrictions, our model allows for installation costs and maintenance costs to be compared against the value of decreased time to complete tasks, which allows for the robots to perform more work.

Improved efficiency through modifying actuation outcomes

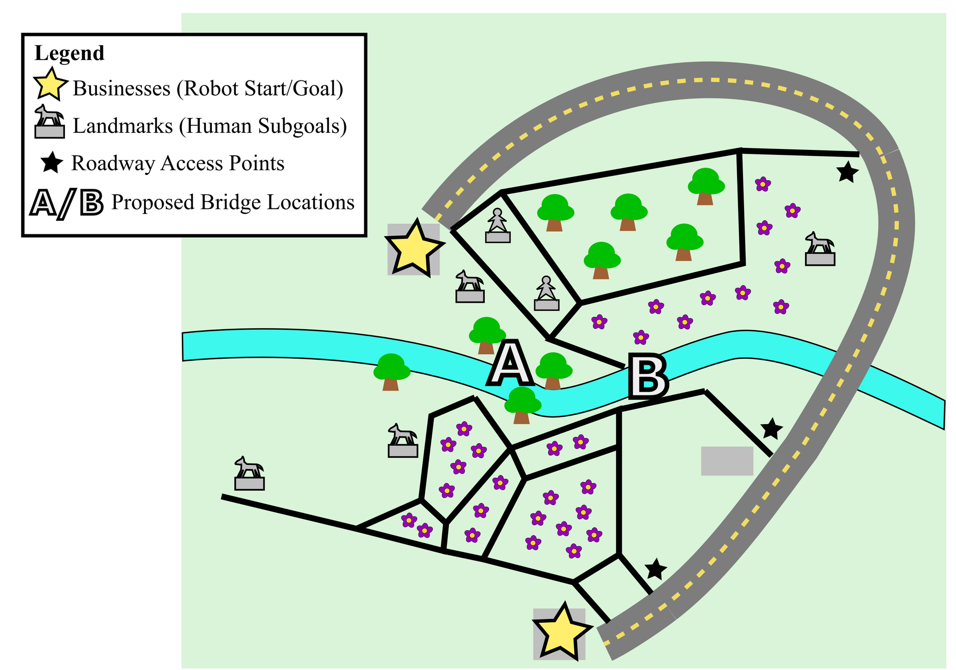


Figure 4: The Bridges in the Park

Two businesses use robots to deliver goods back and forth to each other through a park. The businesses are considering building a bridge through a park at either **A** or **B**. However, the park is also used by a human population, members of which seek to visit several areas of the park before leaving, instead of trying to route the shortest possible path.

Acknowledgments

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