Robotics
Tutorial 1: Robot Floor Cleaner

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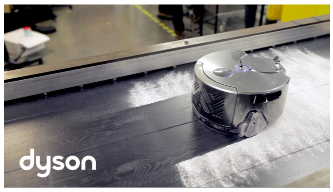


In this tutorial we will consider and discuss the design of a low-cost robot cleaner able to clean the floorspace of typical homes with a vacuum or other cleaning mechanism. The design of such a robot should balance the performance desired of it by users with the technical challenges and cost of equipping it with various capabilities. For now we will assume that this is a small robot with wheels and no ability to manipulate objects or climb stairs! The robot is round, with a diameter of 30cm, and has a maximum speed of 30cm/s and a maximum turn rate of 40°/s.

The following table has unordered lists of some aspects to consider in a robot of this type: 1) requirements that users might have, which we might consider selling points which would differentiate it from other robots on the market; 2) algorithmic/software capabilities we could try to implement on the robot; and 3) pieces of hardware, such as sensors, with which the robot could be equipped.

Requirements/Selling Points	Capabilities	Equipment
Self charging	Free space mappping	Accurate wheel encoders
Fast, systematic cleaning	Localisation	Bump sensors
Kidnap detection/recovery	Global path planning	Camera
Avoids small objects	Reactive obstacle avoidance	Short range obstacle sensors
Self-emptying	Room recognition	Dirt sensor
Fully automatic	Map import/export	Base station
Guaranteed coverage	Object recognition	Wi-fi
Safe near stairs	Motion/gesture recognition	Wheels with tracks
Spot clean	Global mapping	Depth camera
Scheduled room by room cleaning	Wi-fi/PC integration	Room-mounted navigation beacons
Copes with rugs	Random walk movement	‘Cliff sensors’
Cleans room edges well	Navigate to a beacon	Remote control
Detects small objects	Wall following	Virtual walls
	Dense 3D vision	High power vacuum
		Side-facing distance sensors

Consider the following questions:

1. Which elements of the lists above would provide the minimum requirements for a reasonable robot floor cleaner, similar to the first generation Roomba released in 2002?

   Fully automatic, safe near stairs; reactive obstacle avoidance, random walk movement; bump sensors, (short range obstacle sensors), cliff sensors, virtual walls.

2. On the following pages are copies of the floor plan of the ground floor of a typical UK family home. If the robot is turned on in the kitchen, which is temporarily closed off from the rest of the house by a closed door, and navigates in a 'random bounce' style, sketch on the diagram what the trajectory of the robot might look like over its first three minutes. Estimate the fraction of the floor surface of the kitchen it would have cleaned. What will happen if the robot is left to run for a long period of time?

   After a long period of time the robot will keep criss-crossing the area and find its way into most places at least once. Some places will be covered many times. The percentage of floor area covered should tend towards 100.

   The robot will cover 1m in about 4 seconds, so can cross the room in around 10 seconds; a turn at the end will take maybe 5 seconds. So in a minute it can make about 4 traverses of the room. In 3 minutes it should have made about 12 traverses. Perhaps 60% of the floor surface will have been visited at least once.

3. A somewhat more advanced version of the robot has sideways-looking sensors which enable it to follow walls; and a base-station with a charging dock and an infra-red beacon that the robot is able to 'see' if it within sight. Suggest the essential parts of a cleaning algorithm such a robot could use; and on the other part of the first diagram (living/dining room/hall) sketch the kind of path it might follow, assuming that the kitchen is closed off.

   The robot will probably intersperse periods of wall following with criss-crossing and random bounce. It could detect when it has spent too long in a single area using odometry; or just break out from wall following if it has spent too long doing it.

4. Suppose now that a much more advanced robot had *perfect localisation* and came equipped with *a complete map of all the walls and furniture in the house*. Estimate the minimum amount of time for the robot to clean the whole ground floor, executing the best possible navigation strategy.

   The total area of the space is around 30-40m^2. Moving at 30cm/s, the robot sweeps out $0.3^2 = 0.09$m^2 per second. $40/0.09 = 444$s = 7.4 minutes; so maybe 10 minutes with turning time.

5. A real robot which is capable of localisation, whether via beacons placed in the room or using SLAM (Simultaneous Localisation and Mapping), will not have a map of your house in advance when taken out of the box but must explore and build up a free space map as it cleans, using its local sensors to detect walls and obstacles. On the second diagram, sketch what type of trajectory such a robot might take when started in the kitchen.

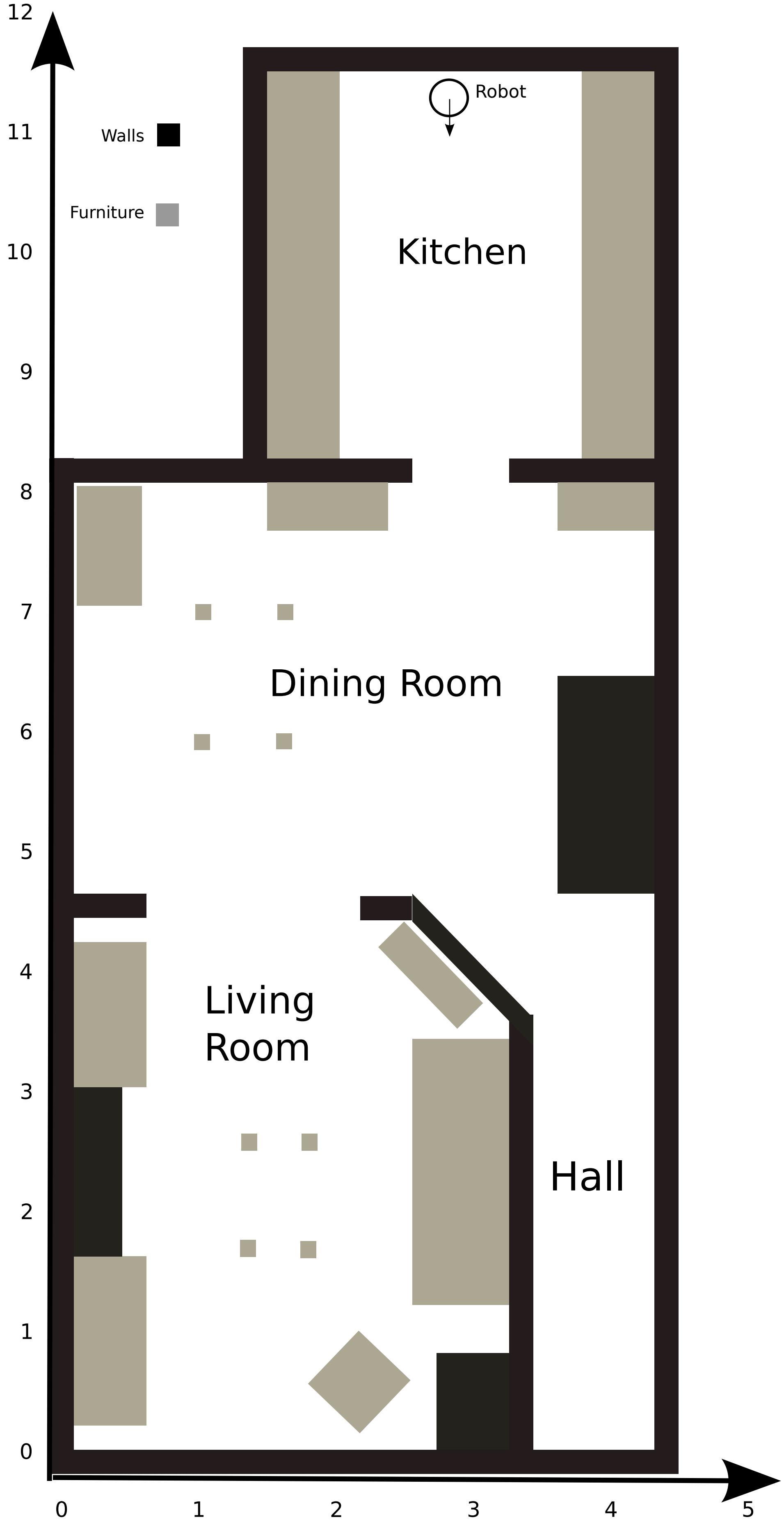
   The robot will clean in systematic stripes or similar, but this will only hold for patches and it will sometimes have to traverse to uncleaned regions.

6. An important consideration in the consumer product market is how different, competing products can be evaluated and compared with each other. For instance, washing machines can be compared in terms of quality of cleaning on different standardised types of clothes and dirt, as well as speed and energy efficiency. Suggest a set of tests which would be suitable for robot floor cleaners.

   The tests suggested so far for robot vacuums test navigation and cleaning capability separately. The robot has a certain amount of time to navigate in a controlled space, with a defined set of obstacles. Its position is tracked with a ceiling mounted camera. The navigation test measures how much of the floor it is able to cover 1, 2 and 3 times. The cleaning capability test weighs the amount of dirt picked up on a controlled run on a surface with a controlled amount of dirt put down.

7. In the future if a robot floor cleaner could be equipped with a practical and low cost dense 3D vision and reconstruction module, what new capabilities might it gain?

   Dense forward-looking vision would enable very precise obstable avoidance and path planning, including the detection of small objects such as Lego bricks or cable. It might decide to try to push such objects out of the way or even collect then. Dense omnidirectional vision could enable room recognition and the use of different cleaning patterns depending on room type.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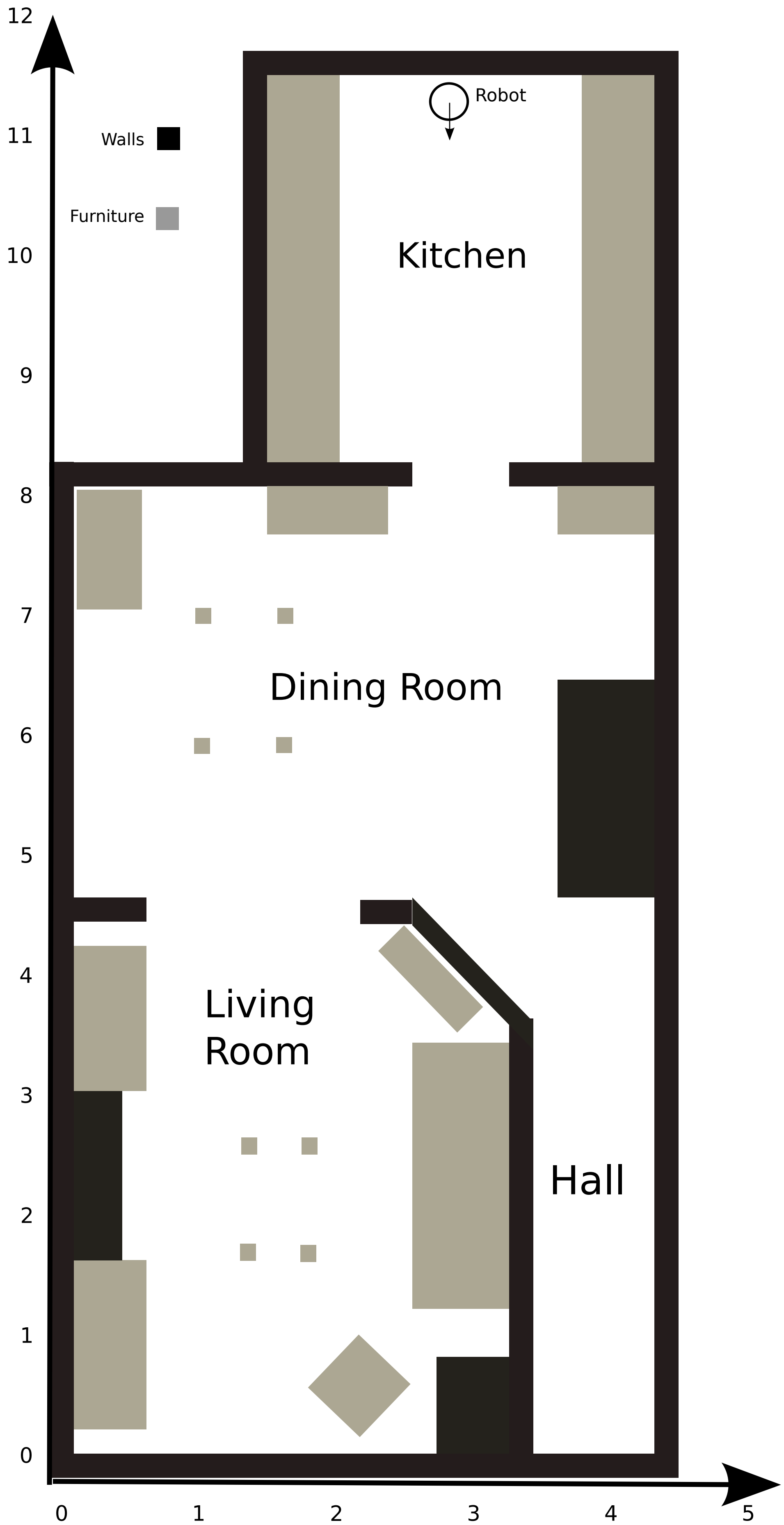

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