Technical Investigation:
Occupancy Grid Maps with Application to DE2Bot

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Executive Summary

This document is a technical investigation of occupancy grid maps for the purpose of applying this technology to a DE2Bot. Occupancy grid mapping is a method of autonomous map creation that utilizes sonar sensors. Each sensor, an ultrasonic rangefinder, processes the distance to the closest object. An occupancy algorithm then assigns an "occupancy" value to each cell on the map ranging from 0 to 1, representing unoccupied and occupied states respectively.

These sensors are effective for detecting objects in a robot's immediate environment, but can lead to incorrect map generation in certain cases. One such case that can lead to inaccuracies is when two objects, relatively close together, are placed far away from an ultrasonic rangefinder. For example, if the two objects are two feet apart, the distance beyond which the two objects will be indistinguishable is approximately 5.67 feet.

Introduction

This paper investigates the use and restrictions of occupancy grid mapping, a method of autonomous map creation, as well as how this technology would function in various situations of application to a DE2Bot.

Technology Review of Occupancy Grid Maps

An occupancy grid map is a 2-dimensional grid represented as a matrix of cells with an "occupancy" value at each location in the immediate environment of a sensor. These values are then computed using an occupancy algorithm to determine which cells are occupied by an object.

Map Creation at Run Time

On a DE2 Bot, there are eight sonar sensors, independently enabled through the SONAREN register. The sensors operate at 25Hz divided between all enabled sensors (if five are enabled, they will each operate at 5 Hz). When a sensor is enabled, it provides its measurement to the corresponding register DIST0-DIST7 in units of mm with a resolution of 1mm and typicall accuracy of ±1cm. Typically, the minimum readable distance is 15cm and the maximum is 6m. Data from registers DIST0-DIST7 is then extracted and processed through an occupancy algorithm to create the occupancy grid map. Additional information on the DE2Bot is available in reference [1].

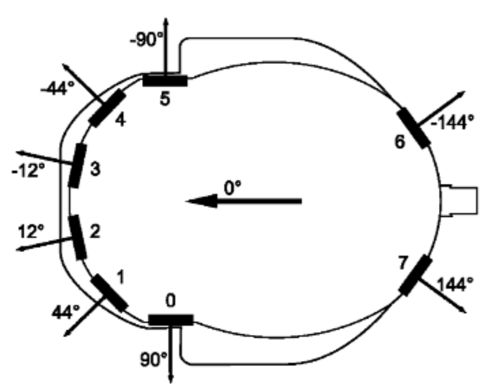

Figure 1. Sonar sensor numbering, positions, and directions on a DE2Bot [1].

Occupancy values range from 0 to 1, representing unoccupied and occupied states respectively. Before a location is explored by the range sensor, a value around 0.5 is assigned to that cell's occupancy data. As time passes, data from the sensor is integrated to determine whether the value at an unexplored cell should be increased or decreased. This data is constantly changing, but can be consolidated into one map at any point during the robot's operation.

The sensors are never entirely accurate, so a probability model is used to determine the likelihood that a cell is actually occupied based on the data collected. Each sensor collects data in a cone-like angular range rather than a straight line, as seen in figure 1. Therefore, even if a cell is truly occupied in the environment, it may only be assigned a value of 0.8, for example, due to its position relative to the sensor's cone. The probability of occupancy decreases exponentially from the center of the cone to its edges. Additionally, the probability that a cell is empty decreases with distance from the sensor. More information on sonar probability models can be found in reference [2] and reference [3].

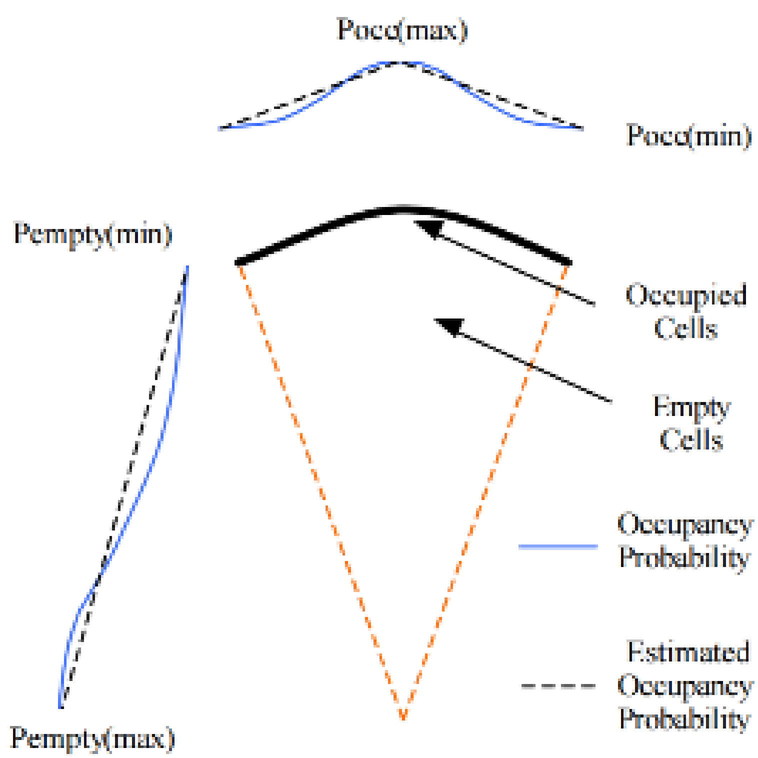

Figure 2. Example of an occupancy probability model for a sonar transducer's angular range [2].

Potential Issues when Using Data from Ultrasonic Rangefinders

When an ultrasonic rangefinder is used for occupancy grid mapping, some data collection errors may occur. The sensor works by emitting a *ping* through a transducer; the time it takes the *ping* to bounce off an object and return to the sensor is used to calculate the distance to the object. Range sensors are used to produce occupancy grid maps, but they present issues that could lower the reliability of results.

For example, range is limited and angular resolution is relatively low, which could lead to uncertainty and trouble differentiating between objects at farther distances. Another issue to consider is the fact that the ultrasonic rangefinder depends on sound waves. Therefore, any object that could deflect or absorb sound waves would be inaccurately examined. Both of these problems could result in incorrect map generation from erroneous data.

Predictions in Specific Situations

In some cases, occupancy grid mapping will face difficulties or fail due to various limitations of ultrasonic rangefinders.

Limitations of Ultrasonic Rangefinders

As mentioned above, one issue with ultrasonic rangefinders is their low angular resolution. This is demonstrated by an example in which two objects are placed two feet away from each other and become indistinguishable at a location far from the robot. Assuming the range sensor has a total sonar beam angle of 20º, a prediction of where the two objects become indistinguishable can be made. As seen in figure 3, the objects are 90º from the robot's direction. This general direction is then converted into an angular range using the half beam-width angle of 10º. Therefore, the arc of uncertainty ranges from 80º to 100º.

For the two objects to be distinguishable, the physical distance between them, two feet, must be greater than the arc length of the sound wave, 20º. The point at which the physical distance is equal to arc length can be calculated as 5.67 feet using the formula $\tan(\alpha/2) = rD/2$ where the angle α is 20º, the distance r is to be solved for, and the diameter D between the two objects is two feet.

In general, the cells measured for grid mapping between two objects diminish with distance from the sensor, leading to worse accuracy. This negative effect could be mitigated with a higher angular resolution or grid resolution. At any distance beyond 5.67 feet in this example, both objects are within the sensor's cone and thus there is uncertainty, indicating one of the limitations of ultrasonic rangefinders for the use of grid mapping.

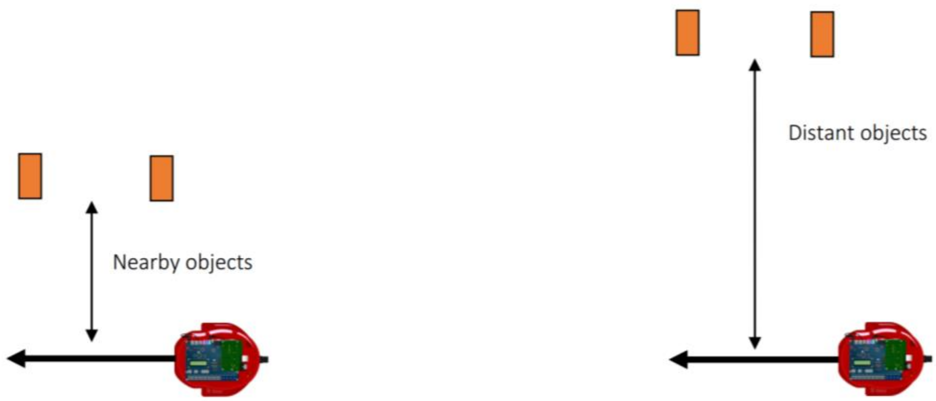

Figure 3. Diagram illustrating the test case of detecting nearby objects in contrast to distant objects.

Works Cited

[1] K. Johnson, "DE2Bot User's Manual," Georgia Institute of Technology, 2016. Available: http://powersof2.gatech.edu/resources/DE2Bot/DE2BotUsersManual_v4.pdf. [Accessed: 04 Oct. 2016].

[2] V. Varveropoulos, "Robot Localization and Map Construction Using Sonar Data," The Rossum Project, pp. 1-3. [Online]. Available: The Rossum Project, http://rossum.sourceforge.net [Accessed: 27 Sept. 2016].

[3] A. Milstein and X. Jing, "Occupancy Grid Maps for Localization and Mapping, Motion Planning," 2008, pp 1-3. [Online]. Available: InTech, http://www.intechopen.com/ [Accessed: 04 Oct. 2016].