An Accurate Navigation System for Robots

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Abstract

It is possible to develop an accurate and relatively low-cost navigation system for robots. This system uses sonar signals for communications between fixed beacons and the robot. Since it uses sonar, it is equally useful for both land and underwater navigation. This navigation system is based on the principle that if you know the distance between yourself and three beacons at known coordinates, you can compute your *(x,y)* coordinates using the mathematics of *trilateration*. The distance from the robot to the fixed beacons is computed based on time of flight of the sonar signal and speed of sound.

Introduction

The basic idea of this beacon navigation system came from the ideas of Prof. Keith Doty and Masters student Kevin Hakala at the University of Florida. The work done to apply this idea to the LawnNibbler™, an autonomous lawn mower, can be found in Kevin Hakala's thesis. This paper outlines the work being done to improve this system to make it more accurate and more robust.

This improvement in accuracy and robustness will be achieved in several ways. First, the properties of sound need to be taken into consideration. The speed of sound is not a constant. In air, it depends mainly on temperature. In water, it depends on temperature, salinity, and depth. By using sensors to take these variables into account, accuracy is improved.

There are also the issues of what to do if, for a period of time, the robot is unable to locate three beacons and how to take advantage of a situation where the robot is able to locate more than three beacons. If the robot has fewer than three beacons to work with, it should be able to use whatever information it does have from remaining beacons with information it has learned in the past and dead-reckoning techniques to maintain a fairly accurate estimate of its position for a certain period of time.

If the robot has more than three beacons, it can use them to get an even more precise measurement of its position. Since there is noise present in all sensors, the measurement of the robot's position can't be exact. If it has four or more beacons, it can better correct for this noise.

By working in this area, an accurate, robust and useful navigation system can be developed.

Trilateration

The method used to compute the robot's precise coordinates from known distances to fixed beacons is trilateration. The robot first finds the distance between itself and three or more beacons. It does this by sending out a sonar pulse. Any beacon receiving the pulse responds with its own series of pulses, which communicate its identity. Each beacon's fixed coordinates are stored in the robot's memory. Based on the time measured between sending the signal and receiving the response, the robot knows the distance between itself and the beacon.

Once the robot knows the distance between itself and at least three beacons, it can compute its position since the coordinates of each beacon is known.

Accuracy

The speed of sound is not a constant. In air it depend heavily on temperature. In water it also depends on salinity and depth. The speed of sound in air depends linearly on the temperature. Speed versus temperature is plotted in figure 1, for T= 0 to 50 degrees Celsius.

As can be seen in the figure, a bad assumption about a constant temperature can lead to serious errors in computation. For example, at 10°C sound travels 40 meters in 0.1189 seconds. If the temperature was assumed incorrectly to be 30°C, the robot would believe the sound had traveled 41.39 meters (off by 1.39 meters!).

To correct for this problem, the robot needs to use the formulas for the speed of sound in air and water as well as various sensors to measure temperature, salinity, etc. The speed of sound in air is

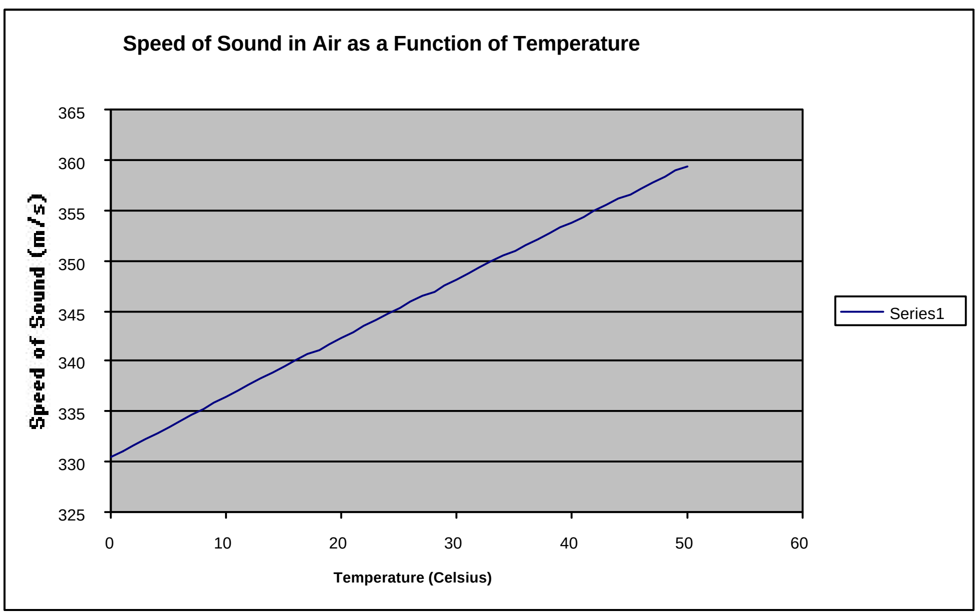
$c = 20(273 + T)$, T=°C, c=m/s

The speed of sound in water is:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S-35) + 0.016Z$$

T=°C,S=salinity(parts per thousand), Z=depth(meters), c=m/s

Figure 1



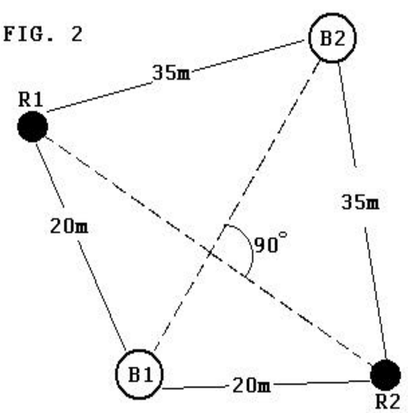
The robot can also take advantage of situations where it is able to locate more than four beacons. All sensors have noise associated with them. For this reason, the calculated position of the robot is never precise. If it can locate more beacons, it helps reduce the built-in error.

Robustness

The robot needs to handle situations where it is temporarily unable to find three beacons. It should be able to keep a relatively accurate idea of its position for a period of time. The best way to accomplish this is to take advantage of information gathered in the past.

If the robot only loses one beacon, but still can find two beacons, it can keep a precise idea of its location. Using the distance between itself and the two beacons, the robot knows it must be at one of two points on a line perpendicular to the line connecting the two beacons. For example, in fig.2, the robot knows it is 20 meters from beacon 1 and 35 meter from beacon 2. The two possible locations of the robot are shown.

FIG. 2



B1 = beacon1
B1 = beacon2
R1 = possible robot location
R2 = possible robot location

If the robot knows that at the last time it computed its position from all three beacons it was west of the two beacons, it can assume that it is still on the west side and rule out the others location. The robot can continue to keep an accurate measurement of its position indefinitely if it makes good use of information such as heading.

If the robot is only able to locate one beacon, it is much more difficult to keep and accurate idea of position. But the robot can use that beacon along with other information and sensor data to do dead reckoning. When the robot knows it is a certain distance from a single beacon, it knows it is located somewhere on a circle whose center is the beacon and whose radius is that distance. If it makes good use of other information, the robot may be able to have an accurate idea of its position, with increasing uncertainty as time passes. There are ways to reduce the uncertainty and error.

One way to do this is to learn as much as possible when three beacons can be found. If the robot has sensors to measure its heading, velocity and time elapsed, it can estimate what its position should be based on the last known position. Obviously, this estimate is prone to increasing error as time passes. But, if the robot compares its estimated position to its actual position each time that it is computed, it can learn certain patterns and factor them into future estimates. For example, for a wheeled robot, if the left wheel turns slightly faster than right wheel, the robot will always tend to veer to the right. This is a pattern the robot can learn to compensate for.

Using these techniques, the navigation system can be made to be very robust. The number of beacons and their placement should be chosen so that the robot will have to rely on less than three beacons as seldom as possible. But these situations can be successfully dealt with.

Current Research

Currently, a simulator is being developed using Mathematica to test and refine these ideas. The goal is to test how certain algorithms and learning techniques deal with problems such as sensor noise, wheel slippage, and other common problems, especially when the robot is forced to do dead reckoning.

Future Work

After the work with the simulator has been completed, the next goal is to test the idea in the real world. A robot will be built with a sonar transceiver and sensors to measure heading and speed and environmental conditions. The best algorithms and techniques from the simulator will be tested and refined.