Experimental modelling of time-of-flight sonar

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7/4/97

Abstract

Sonar rangefinders are commonly used in mobile robotics for map building, navigation, and localisation. All robot sonar systems must, implicitly or explicitly, use a model of the sonar sensor. However, no systematic attempt has been made to experimentally model the behaviour and reliability of sonar range returns. This paper describes an empirical model of sonar time-of-flight, derived from a large quantity of data collected with a single polaroid ultrasonic rangefinder.

Fifty sets of sonar readings, each consisting of one reading at each of 183 angles, were taken from each of 40 sensor positions in a heterogenous environment containing one extended rough brick wall and one extended smooth wood wall. For both walls, readings were collected by sensor distance from the wall and beam incidence angle, discarding those readings whose beam passed sufficiently close to a corner or obstacle that may have influenced the range reading. Range returns from the brick wall were initially modelled by distance to the wall along the beam direction, but a better fit was obtained by the distance to the wall in a direction displaced 3.6 degrees inwards from the beam direction. The variability of the range return from the brick wall was found to be small for incidence angles close to perpendicular, and larger for more oblique angles. This was modelled by assuming a constant angular error. It was noted that, for oblique angles, the mean readings from laterally displaced sensor positions, with the same incidence angle and perpendicular distance from the wall, showed significant differences. This suggests that, for oblique returns, the returned range depends on factors other than the sensor position and orientation, such as the precise geometry of the rough wall at the reflection point.

Range returns from the wood wall were found to be close to the sensor distance for angles close to perpendicular, and took larger, unpredictable values for oblique angles, presumably due to multiple specular reflections. The probability of returning the sensor distance was exactly 1 for small incidence angles and fell sharply to zero at 24 degrees, with a slight dip at 14 degrees and a slight secondary peak at 31 degrees. The angles at which the sharp fall, dip, and secondary peak occur were independent of robot position. However, the probabilities of return near these angles were found to differ significantly with sensor position, even for a constant distance from the wall. This again suggests that the probability depends on other factors, such as the existence of objects that could cause multiple specular reflections.

The models presented in this paper extend and correct those currently used in many robot sonar systems, particularly in the case of oblique incidence angles. We also describe circumstances under which sonar ranges are reliable, in that they depend only on the reflecting wall's position and orientation, and circumstances in which they are unreliable, in that they depend on other factors such as the local geometry of a rough wall or the positions of other objects in the room.

Proc. TIMR 97 - Towards Intelligent Mobile Robots, Manchester 1997.
Technical Report Series, Department of Computer Science, Manchester University, ISSN 1361 - 6161.
Report number UMCS-97-9-1. http://www.cs.man.ac.uk/csonly/cstechrep/titles97.html