VISUALIZATION OF MOBILE ROBOT ENVIRONMENTS FROM ACOUSTIC SENSOR DATA

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Abstract

This paper describes an approach to the visualization of data from mobile robot sensors which use acoustic echo-location to determine object distances. Acoustic distance measurement is problematic in that echoes may fail to be returned to the source, range assessments may be inaccurate, and ghost readings may also appear in the data. The method described maintains a geometric model of the perceived environment which supports the reduction of ambiguities in the sensor data. The approach is also tolerant to odometry inaccuracies. The aim is to develop a display method which will provide sufficient spatial consistency and comprehensibility to support telerobotic navigation tasks over a low-bandwidth link.

1 Introduction

A fundamental problem of telerobotics is deciding how to deal with sensor datasets which may be contradictory or incomplete. Human ability to handle ambiguity and uncertainty in spatial relationships is, in general, far superior to that of current AI systems. It therefore follows that for tasks such as teleoperation it may be better to draw upon the considerable power of human perceptual experience in order to tackle such difficult problems.

This poses the question: 'What is an appropriate way to present robot sensory data in a form amenable to human interpretation?'. Clearly many solutions are possible. However, it is recognised that human spatial understanding is largely *qualitative* in nature. Perception of locality is always judged relative to some feature of the environment [3]. This suggests that the visualization of significant landmarks is of greater importance than the presentation of quantitative information, such as precise distance indicators. A relatively simple approach to the visualization problem is described here, which is targeted more at the presentation of general environmental features than it is at accurate map production.

A Nomad 200 mobile robot is being used in the research to allow the evaluation of visualization methods using real-world data [6]. Amongst its many sensing devices are sixteen acoustic range finders, each with an operating range of around ten metres (Figure 1). These are arranged to provide the robot with a full 360 degree sensing capability.

The robot control software supplied by the manufacturer features a simple graphical utility for the visualization of sensor data [5]. The approach taken is to render a 'scatter plot' of raw sensor readings, whose distribution forms an approximate plan view of the robot's perceived

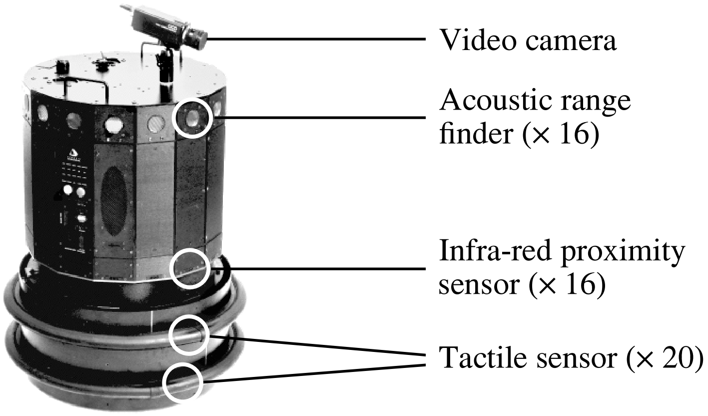

Figure 1: The Nomad 200 mobile robot

environment. No attempt is made to remove noisy data from the rendered image, which makes scene interpretation extremely difficult, particularly for remote navigation tasks. However, with effort a limited degree of teleoperation is possible using such an interface [4].

2 Acoustic sensing

Acoustic range finders determine obstacle distances using 'sonar' echo-location – ultrasonic pulses are fired into the environment, and the time taken for their return is measured. The raw data obtained from such sensors tends to be of limited resolution and accuracy, and is often noisy. For this reason, robotics researchers sometimes choose to develop their control algorithms using simulated environments, thereby avoiding the need to deal with the idiosyncrasies of real-world sensing [1]. For applications such as telerobotics in which environment simulation is not an option, the characteristics of low-quality data must be considered if coherent information is to be supplied to the user.

2.1 Causes of low-quality sonar data

The passage of an ultrasonic pulse around an environment is a complex process, with a behaviour reminiscent of the transport of light rays – a topic well-known to the computer graphics community [2]. However, in the context of acoustic sensing some general situations can be identified which may lead to measurement anomalies:

Lost echoes. If an acoustic pulse strikes an object with a large angle of incidence the signal may not return to the source. Object size and geometry also affects the probability of an echo return: concave corners are generally good reflectors, whereas convex forms are not. The loss of an echo may cause potential obstacles in the environment to go unobserved.

Inaccurate measurements. When an echo is returned, the distance which is inferred from the signal delay may be unrepresentative of the true distance to the nearest obstacle in the acoustic path (if the near portion of the detected object a poor reflector, for example).

Ghost readings. An acoustic pulse may experience multiple reflections around the environment and be misinterpreted on its eventual return. This may erroneously indicate the presence of a non-existent obstacle.

Figure 2 summarises the problems of acoustic sensing. An ideal sensor would consistently report the precise distance to all objects within its operating range, and would never signal the presence of non-existent obstacles. In contrast, real sensors may misjudge distances, fail to detect obstacles within range, and be unable to differentiate between genuine and ghost signals.

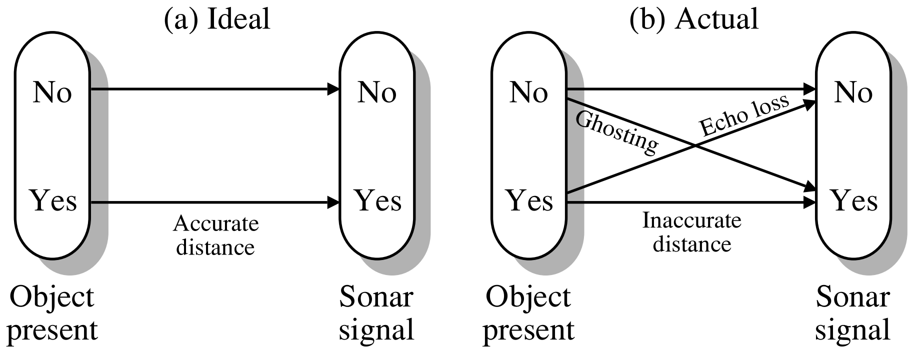

Figure 2: Summary of acoustic sensing characteristics

3 An approach to acoustic data visualization

An environment visualization algorithm is described which encourages the removal of transient ghost objects from the displayed image and which can help to 'fill in the gaps' when echoes are lost. It is also capable of setting the current sensor information within a wider exploration context, thereby providing a relatively coherent and recognisable picture to the robot operator.

The approach taken is to construct a geometric representation of the robot's perceived environment, which is then *refined* over time by incorporating more up-to-date sensor measurements. Polygon *union* ($\cup$) and *difference* ($-$) operations are used to edit the geometry [7]. The method is not intended as a means of precise map production, and does not require highly-accurate odometry in order to function.

Figure 3 depicts a 360 degree scan of a room (shown dotted) as perceived by the Nomad 200. A scan represents a single set of readings from all sixteen acoustic sensors, each of which either returns a distance reading, or a flag which indicates that no echo was returned. The robot lies at the centre of the image, with the outer 'circle' (C) representing the maximum working range of the acoustic sensors. Several subregions have been identified in this simple visualization:

Free space regions (F), the extents of which are inferred from echo timings. Ghost readings (*) may cause some of the data to be unrepresentative of the actual room shape.

Obstacle regions (O), which bound the perimeter of the free space areas. As the depth of objects cannot be measured directly, each is rendered with a constant 'thickness' of arbitrary magnitude.

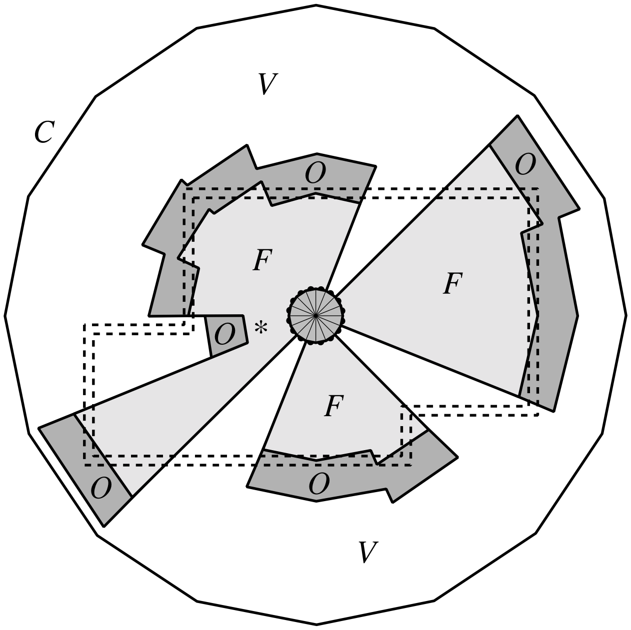

Figure 3: Plan view of a typical set of scan data

Void regions (V), which represent areas of uncertainty in the image. Void regions may indicate that no echo was returned to a given sensor (either due to echo loss or simply because no obstacles are within range), or they may represent hidden regions which are masked by nearby obstacles.

3.1 Data refinement

The geometric description which is presented to the operator may be improved by incorporating data from later scans, in which either the robot's position or the environment itself has changed. This is an iterative approach to the visualization problem: the current scan dataset is incorporated within the scene model, the revised geometry is rendered, and the next scan is then processed.

Let F_{old}, O_{old} and V_{old} represent the free space, obstacle and void regions identified before the current scan s is processed. The following procedure is applied to generate a new description of the environment, which fuses the current scan components (F_s, O_s and V_s) with the old description:

1. The robot model is repositioned in response to any odometry updates.
2. New free space regions F_{new} are calculated:

$$F_{new} = (F_{old} \cup F_s) - O_s \tag{1}$$

3. New obstacle regions O_{new} are calculated:

$$O_{new} = (O_{old} \cup O_s) - F_s \tag{2}$$

4. Void regions represent whatever is left over within sensor range:

$$V_{new} = C - (F_{new} \cup O_{new}) \tag{3}$$

The O_s term in Equation 1 is of particular significance in the visualization of *dynamic* environments, in which approaching objects may cause the free space in the robot's vicinity to decrease in size. The F_s term in Equation 2 plays a similar role for receding objects.

The refinement process is illustrated in Figure 4. Note that the latest scan data (which is of greatest importance for real time control) always appears in its entirety within the fused dataset. In addition, the method embellishes the image with an exploration history, reduces the extent void regions, and encourages the overwriting of ghost obstacles from earlier scans. No attempt is made to prevent the introduction of *new* ghost readings which may form part of the current scan. Such readings generally appear as transient objects within the presented image, and may therefore be treated with suspicion by the operator.

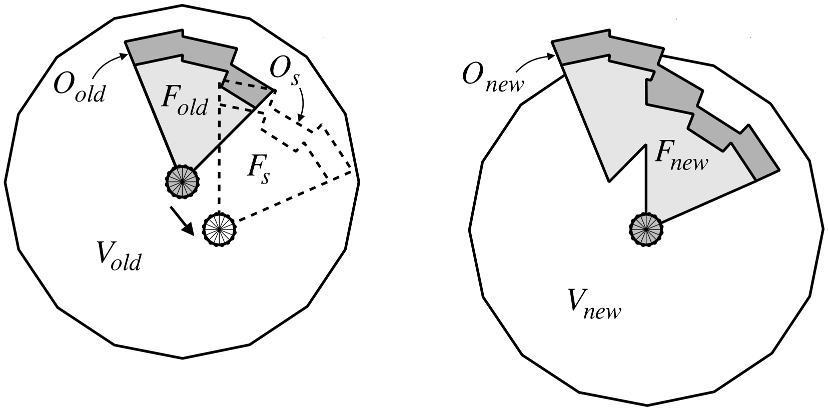

Figure 4: Merging a new scan dataset

4 Conclusions

An acoustic data visualization method has been described with the following properties:

- Regions of uncertainty in the display may be reduced in extent through the fusion of several sensor datasets collected as the environment is explored. The robot's immediate locality is set in the context of a wider exploration history, enabling the self-orientation of the operator with respect to landmarks which were encountered previously.

- Historical datasets are always superseded by more recent sensor information, thereby allowing the visualization of non-static environments. Ghost surfaces may be removed as a by-product of this operation. The most recent scan data always appears in full within the image.

It should also be noted that the real-time transmission of acoustic scan data has extremely modest bandwidth requirements (a few tens of bytes per second). This permits the implementation of a graphics-based telerobotic navigation facility over a low speed connection, such as a serial communication link.

4.1 Further work

To date, a distributed environment has been developed in which acoustic datasets may be acquired and rendered in real time, and which also supports the remote control of robot motor functions. The implementation of the refinement algorithm is close to completion.

A number of experimental issues are still to be addressed. To begin with, a study of the effectiveness of the new visualization method for remote navigation tasks is to be performed. The existing raw data plotting method [5] will be used as a baseline.

Secondly, an evaluation of 3D visualization methods is planned, in which obstacle regions are extruded vertically to form free-standing solids. This will permit the display of natural perspective views of the environment 'from within', which may be used to supplement the user's understanding of the plan views described. Such an approach would also allow images captured by the robot camera to be mapped onto the upright obstacle surfaces as an aid to feature recognition. A large-screen stereoscopic projection system is to be used for 3D image display.

References

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