Use of Dempster-Shafer Conflict Metric to Adapt Sensor Allocation to Unknown Environments

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Abstract

This paper considers a robot with multiple sensors navigating an unknown, heterogeneous environment. In these cases sensor errors may produce an unsuitable model of the world. For example, observations from a laser range finder often produce accurate maps in indoor environments but when glass walls are encountered, the laser sees through it and the accuracy degrades. The approach taken is based on prior work with the Dempster-Shafer Con metric showing that the Gambino indicator, without the use of a ground truth, can identify when a model of the world is inconsistent. This study investigates the impact, in terms of overall map quality, of applying this new capability. Experiments with a mobile robot carrying a ring of sonar and a laser range sensor operating in indoor environments shows a 19.6% to 77.4% improvement when a switch to a more suitable sensor was triggered by the Gambino indicator. While these results are preliminary, this is a major step toward self-aware autonomous agents that can identify anomalous situations and adapt to the unknown appropriately.

Introduction and Approach

An autonomous robot entering an unknown environment has only its sensors to provide the information it needs to navigate safely and carry out its assigned mission. This is not a problem if sensing provides consistent and accurate information, but how does such a robot detect when its sensors become unsuited for its surroundings? The findings in (Carlson & Murphy 2005) indicated that the Gambino indicator may provide a solution to this problem by identifying when an occupancy grid became inconsistent without the use of a ground truth. This short paper summarizes recent work exploring the application of the Gambino indicator to adaptively improve overall map quality in unknown environments.

To improve an autonomous robot's ability to adapt to unknown environments that are unfavorable to one of its sensors, an indicator must: *alert the system when a sensor is in use that is unsuited for the robot's environment*, not *raise false alarms for minor inconsistencies in readings from appropriately used sensors*, and *provide improvements in sensing as compared to the naive strategy of always using the most sophisticated sensor available*. The objectives of this study are to show that the Gambino indicator meets these criteria.

This study applies the Gambino indicator to detect and respond to interpretation inconsistency. One motivation for this problem comes from *sensing anomalies* which refers to *cases in which the physical sensor(s) are working within the manufacturer's specifications but the readings would lead to an incorrect interpretation of the environment*. Our approach provides a means of detecting sensing anomalies in unknown environments by assuming that such environments are consistent. For the purposes of this study consistency is defined as *free of conflict* where conflict, ϕ, is defined as the intersection of mutually exclusive hypotheses.

Given this assumption, an appropriate measure of *inconsistency* in a model of that environment can be used to detect sensing problems. If conflict appears in a model built from sensor readings it was caused by one or more of the following: a flawed model design, inaccurate sensor readings, poor localization of the robot within the environment, or over-simplified sensor models. This formulation of consistency allows conflict to be used to detect a variety of sensing and modeling problems. For example in (Gambino, Ulivi, & Vendittelli 1997) an occupancy grid was used to model a dynamic simulated environment where the sensor readings were perfectly accurate, thus a conflict-based metric could be developed to detect changes in the environment. This study uses occupancy grids in a real, static environment where sensing anomalies are assumed to generate significantly more conflict than the other three factors.

The Dempster-Shafer conflict metric, Con (Shafer 1976), or the $conflict$ belief mass in Smets' variant (Smets 1990) of Dempster-Shafer, provide theoretically suitable measures of inconsistency in a set of evidence. Previous work (Carlson & Murphy 2005) shows that the Gambino indicator (adapted from (Gambino, Ulivi, & Vendittelli 1997)), which uses Smets' variant, can be used to classify the sensing situation as *degraded* (false negative rate of 7%) or *normal* (false positive rate of 0%) and estimate the overall map quality for both sonar and laser readings.

The results from two response scenarios are included in this paper. Each scenario began by using either the laser or sonar sensors to build a map of the surrounding environment using Dempster-Shafer mapping while the Gambino indica-

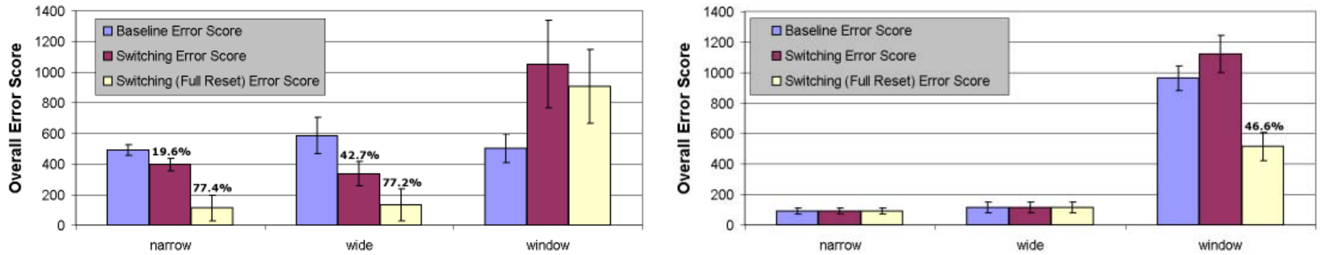

Figure 1: Mean error scores for each response strategy compared to the baseline when either the sonar (left chart) or the laser (right chart) was the initial active sensor. The sample size for each mean varied by testbed as follows: *narrow* n=170 (10 samples for each trail), *wide* n=110, and *window* n=170. Error bars show the standard deviation. Where improvements were made, the percentage of improvement is shown above the improved means.

tor monitored the sensing situation. In the *switching* scenario the sensing manager responds by switching from the current sensor to an inactive one. In the *switching with full reset*. The sensing manager responds by resetting the entire grid prior to switching sensors.

Experiments and Results

A series of 270 experiments using real sensor data from a Nomad 200 robot with sonar and laser sensors were conducted to ascertain whether the Gambino indicator could improve an autonomous robot's ability to adapt in unknown environments. The readings were collected in multiple trails in three indoor hallways: *narrow* (17 trails), *wide* (11 trails), and *window* (17 trails), known to cause sensing problems for sonar (all three) and laser (only *window*) sensors. The raw sensor readings were registered to a Dempster-Shafer occupancy grid (see (Murphy 2000)) while the Gambino indicator monitored consistency within the resulting map. The system responded to any warnings issued by the Gambino indicator by switching to a different sensor. The results were evaluated in terms of a quantitative map quality metric based on the arithmetic difference between ground truth maps (manually built from measurements of the hallway's dimensions) and those produced by the sensor readings.

The experimental results, given in Figure 1, show that improvements in overall map quality ranging from 19.6% to 77.4% are possible by switching sensors when warned provided by the Gambino indicator. They also show improved map quality (by 46.6%) over a strategy that uses the most sophisticated sensor (in this case the laser) at all times. Figure 1 shows the mean and standard deviation the overall error scores for each strategy as compared to the baseline, broken down by hallway.

The *switching* strategy results showed that warnings provided by the Gambino indicator enabled the sensing manager to reduce the overall error by at least 19.6% and at most 42.7% in the *narrow* and *wide* hallways. In these hallways using the Gambino indicator to detect inconsistency in the map enabled the system to adapt to the environment by switching to a more accurate sensor. However, the overall map quality in the *window* hallway decreased by factor of two due to errors caused by the large glass windows.

The *switching with full reset* strategy results showed that more significant improvements, 77% over baseline, can be achieved by removing all the information from the map prior to switching from the sonar to the laser sensor. As in the *switching* strategy, these improvements were recorded for the *narrow* and *wide* hallways, while the overall map quality dropped relative to the baseline in the *window* hallway. This decrease was made less severe by removing errors introduced by the sonar prior to switching sensors.

The scenarios in which the laser was used initially show that the Gambino indicator did not fire warnings in the *narrow* and *wide* hallways, where sensing anomalies were not present. Warnings were fired in the *window* hallway where the laser was unable to consistently sense the right-hand (windowed) wall. In the *switching with full reset* strategy erasing the map prior to switching provided an overall improvement in map quality of 46.6% despite the superiority of the laser sensor in terms of accuracy.

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