9.2.1 Multi-Sensor Fusion

Robots are often equipped with more than one type of sensor. Hence, a natural objective is to integrate information from more than one sensor into a single map. This question as to how to best integrate data from multiple sensors is particularly interesting if the sensors have different characteristics. For example, Figure 9.8 shows occupancy maps built with a stereo vision system, in which disparities are projected onto the plane and convolved with a Gaussian. Clearly, the characteristics of stereo are different from that of a sonar-based range finder. They are sensitive to different types of obstacles.

Unfortunately, fusing data from multiple sensors with Bayes filters is not an easy endeavor. A naive solution is to execute algorithm **occupancy_grid_mapping** in Table 9.1 with different sensor modalities. However, such an approach has a clear drawback. If different sensors detect different types of obstacles, the result of Bayes filtering is ill-defined. Consider, for example, an obstacle that can be recognized by one sensor type but not by another. Then these two sensor types will generate conflicting information, and the resulting map will depend on the amount of evidence brought by every sensor system. This is generally undesirable, since whether or not a cell is considered occupied depends on the relative frequency at which different sensors are polled.

A popular approach to integrating information from multiple sensors is to build separate maps for each sensor type, and integrate them using an appropriate combination function. Let $m^k = \{\mathbf{m}_i^k\}$ denote the map built by the k-th sensor type. If the measurements of the sensors are independent of each other we can directly combine them using *De Morgan's law*

$$p(\mathbf{m}_i) = 1 - \prod_k \left(1 - p(\mathbf{m}_i^k)\right) \tag{9.9}$$

Alternatively, one can compute the maximum

$$p(\mathbf{m}_i) = \max_k p(\mathbf{m}_i^k) \tag{9.10}$$

of all maps, which yields the most pessimistic estimates of its components. If any of the sensor-specific maps show that a grid cell is occupied, so will the combined map.