Applied Estimation Lab 2—Particle Filter

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1 Part I—Preparatory Questions

1. Particles are used to represent a hypothesis of a single possible state of the system, which are drawn from some probability distribution. A single particle alone is not particularly useful, as it has no explanatory power about the possbile distribution of the true state. Instead, a large number of particles are used to represent belief in the form of a particle cloud.

2. The *importance weight* is a weight assigned to each particle to indicate its expressive power as a part of the particle cloud. Particle weights depend on the measurement update. If the measurements that we find by simulating a set of measurements from the particle's state closely match the measurements given by our true system, the particle is given a proportionally higher weight. If the measurements are a poor match, then it receives a low weight. As such, a higher weight indicates a higher probability of the system being in that state. The *target distribution* is the true state of the system. We do not know what the actual distribution of the true state is, but if it were possible to have an infinite number of particles, then we could represent the target distribution exactly. The *proposal distribution* is the distribution that is represented by the particles. This distribution is the target distribution, approximated by a finite number of particles. In the particle filter, we try to estimate the target distribution by the proposal distribution, the shape of which is defined by the positions and importance weights of a particle cloud.

3. Particle deprivation occurs as a result of the resampling step of the filter. While it is more likely when there are not enough particles to cover all of the relevant regions of the target distribution, it happens in particle filters with any number of particles due to the nature of random sampling. The danger of deprivation is that it can result in there being no particles near the true state of the system.

4. If instead of resampling we simply updated weights for the particles, we would end up with particles in areas of the space which simply did not need representation because the probability of the true state being in that area is very low. These particles would be wasted representing this space. If we instead resample and represent the areas in which the system has a high probability of being, then we cover more positions that might be the true state. In essence, we would like to have the number of particles in a region proportional to the probability of the state of being in that region.

5. The average of the particle set is usually not a good representation of the set, particularly in cases where the proposal distribution is multimodal, that is, when it has multiple

peaks, or there are multiple groups of particles. In the case of a two-peaked distribution, the average will end up in the centre of the two groups, and is not representative of any state in which the system is likely to be.

6. To make inferences about the probability of states between particles we can use histograms or Gaussian kernels. In the case of histograms, we can find the probability of the system being in an intermediate bin by interpolating the values of two adjacent bins. With Gaussian kernels, we can place a Gaussian on each particle, with a height proportional to the weight of the particle and with the same variance for each particle, depending on some uncertainty measure. Having summed all of these Gaussians, we could get information about intermediate states by looking at the resulting distribution.

7. Sample variance is the variability introduced due to random sampling from a distribution. As we sample only a certain number of times, the statistics of the new distribution will vary slightly from that of the original. This can cause problems as if the sample variance is too large the representation of the true belief will not be good. There are a number of techniques available to perform variance reduction. One technique is to increase the time between subsequent resamplings. Another is to use low variance sampling, which uses a stochastic process to select samples instead of sampling them independently.

8. If the pose uncertainty is large, the target distribution has a large spread, and therefore may have many peaks in different places which must all be represented to have an accurate proposal distribution. Do do so, we need a large number of particles. Thus, for a higher pose uncertainty, a larger number of particles are required.