2 Mapping and Navigation

Mobile robots and animals alike require the ability to move around in their environments. For a large number of animals such as insects, this ability is provided by reactive movement schemes. With an appropriate set of reactive behaviours an insect can function quite well in complex environments. However, there is a limit to what can be achieved through pure reactivity. A whole class of navigation problems become solvable if an animal or robot is able to form some sort of map of its environment.

Research on the topic of mapping and navigation can be split into two areas. One area has focused on how animals move around and function in their habitats, whether the animal is an ant scurrying around on desert sand dunes (Muller and Wehner 1988), or an English taxi operator driving passengers around London (Maguire, Frackowiak et al. 1997). Popular study subjects in this area of research include rodents, primates, humans, and bees. By examining the capabilities of these biological agents both in nature and controlled environments, researchers have formed a number of models of the actual physical and neurological mechanisms driving their navigation systems. The extent of the research has varied, from purely theoretical analysis (Abbott 1994; Eichenbaum, Dudchenko et al. 1999; Hahnloser, Xie et al. 2001), to validation through testing of software models or testing in simulated environments (Borenstein 1994; Touretzky, Wan et al. 1994; Balakrishnan, Bhatt et al. 1998; Stringer, Rolls et al. 2002; Chavarriaga, Sauser et al. 2003; Koene, Gorchetchnikov et al. 2003), to deployment of models on actual robotic platforms (Arleo 2000; Krichmar, Nitz et al. 2005).

Roboticists have generally had a different motivation driving their mapping and navigation research – the desire to produce functioning robots. The inherent uncertainty of the sensors used on robots has led to a convergence of the most successful robotic mapping and navigation systems – they are all probabilistic to some degree (Thrun 2000). Most methods have as their basis one or more of three different probabilistic algorithms: Kalman Filter, Expectation Maximisation, or particle filter algorithms. However, there is a large range of methods within this banner of probabilistic systems (Thrun 2002). The robot platform, sensor types, and environment all affect the way in which a mapping and navigation system is developed.
This and the following 4 chapters examine the research that has been conducted in both the robotic and biological mapping and navigation fields. Their purpose is as follows:

1. Introduce the mapping and navigation problem and discuss the various components of the problem.
2. Review the core probabilistic algorithms and the robotic mapping methods that use them.
3. Investigate the capabilities of biological systems.
4. Review the mapping and navigation performance of state of the art models of the rodent hippocampus – the most thoroughly understood biological system in this field.
5. Identify key issues in the field of mapping and navigation and use them to compare and contrast robotic and biological systems.
6. Highlight the middle ground between the probabilistic and biologically-based research areas, and discuss the advantages of developing a method inspired by biological systems but with a primary focus on practical performance.

2.1 The Mapping and Navigation Problem

Mobile robots by definition move around in their environments. Low level robots may function quite adequately in their environment using simple reactive behaviours and random exploration, but more advanced capabilities require some type of mapping and navigation system (Thrun 1998). The purpose of this section is to clarify exactly what is implied by the words ‘mapping’ and ‘navigation’ and to discuss the various capabilities a robot must possess to achieve these tasks.

2.1.1 Localisation and Mapping

When a robot localises, it determines its location within some representation of the environment. The act of localisation can vary greatly in complexity. Take the example of a robot that has just detected it is within a certain range of an infrared beacon. Armed with the prior knowledge that there is a single infrared beacon somewhere in its environment (and hence equipped with a map), the robot now knows that it is within a certain distance of that beacon, effectively localising itself within its map. In another environment an aerial robot may have measured its distance from four artificial landmarks placed on the ground. Armed with the prior knowledge of the landmarks’ positions within the environment (a map), the robot can localise by calculating its position from the distance measurements. It is important to note that the localisation process is entirely dependent on the map the system possesses – without a map the process has no meaning.

Mapping involves creating a representation of the environment. The representation or map can vary; one map might store a set of coordinate locations of trees in a park; another might keep a millimetre resolution grid showing which parts of an office floor have objects on them; yet another may represent the environment as a sequence of images and motor actions. Mapping is inherently linked with localisation – just about all mapping processes require that the robot is able to localise itself at least some of