CHAPTER 1

Introduction

This chapter introduces the field of intelligent robots and gives some examples of application scenarios of robots.

We describe navigation methods used by natural creatures and present the basic concepts for autonomous mobile robot navigation.

Moreover, we identify drawbacks of current navigation methods and derive the aims and objectives of this research. The main contributions are described and an outline of this thesis is given.

1.1 Intelligent Robots

Robots and intelligent machines today impact on modern life in may ways, from industrial manufacturing in factories, healthcare in hospitals, transportation, robotic fire fighters to exploration of the deep sea, planets and space. Many companies have emerged, manufacturing mobile robots for domestic support. The most well known is probably the iRobot Corporation[1] which produces autonomous vacuum cleaners. Other companies manufacture autonomous lawn mowers (Friendly Robotics[2]) or robots for surveillance (RoboWatch Technologies GmbH[3]).

Moreover, large companies have identified the area of robotics as strategically important. For example, the Honda Motor Company, Ltd. started in 1986 with the production of the ASIMO robot as part of Honda's Research and Development robotics program. Even the Microsoft Corporation moved into robotics and designed the Robotics Developer Studio 2008 as a platform for developing robotics applications. "Microsoft views robotics as a significant new market on an accelerating trajectory" said Tandy Trower, general manager of the Robotics Group at Microsoft [Kara, 2006].

Robots have emerged due to the vision of humanity to create skilled and intelligent machines which support humans in daily life. The quest for making robots and machines intelligent has

[1] http://www.irobot.com
[2] http://www.friendlyrobotics.com
[3] http://www.robowatch.com

been, and is still part of intensive research in diverse disciplines such as engineering, artificial intelligence, machine learning and machine vision.

While the concept of robots was established by many creative and visionary historical realisations, physical robots emerged in the twentieth century with the development of the underlying technologies [Siciliano and Khatib, 2008a]. The term *robot* is derived from "robota" meaning subordinate labour in Slav languages and was introduced in the play "Rossum's Universal Robots" in 1920 by Czech Karel Căpek [Căpek, 1920]. The ethics of the interaction of humans and robots were governed by the fundamental laws defined by Russian author Isaac Asimov in his novel "Runaround" [Asimov, 1940].

In early stages, robots were primarily for industrial automation. However, the science and technology of robots, called *robotics*, has been rapidly expanding into challenges of the human world. Recent generations of robots are expected to safely operate in human environments such as homes and workplaces or traffic situations in order to provide services, automated labour and assistance. Figure 1.1 shows several applications scenarios of today's robots.

1.2 Concepts of Autonomous Mobile Robot Navigation

Intelligent mobile robots which are able to perform challenging tasks in unstructured environments such as natural, unpredictable or dynamic surroundings without continuous human guidance are called *autonomous mobile robots*. The capability of navigating an environment is fundamental for autonomous mobile robots to accomplish their tasks and missions. *Robot navigation* is the process of moving a mobile robot autonomously from a position to a goal position along a feasible trajectory. Leonard and Durrant-Whyte summarise the navigation problem in robotics with three questions [Leonard and Durrant-Whyte, 1991a]: "*Where am I?*", "*Where am I going?*", and "*How do I get there?*".

These questions refer to the main tasks in the quest towards truly autonomous mobile robotics: *self-localisation*, that is the estimation of the robot's position with respect to its environment, *mapping* which refers to the acquisition of internal models of the environment from sensor data and *path planning* from the estimated position to a target position using the internal model of the environment.

Numerous approaches exist to navigate an autonomous mobile robot. DeSouza and Kak classify navigation strategies into three groups [DeSouza and Kak, 2002]:

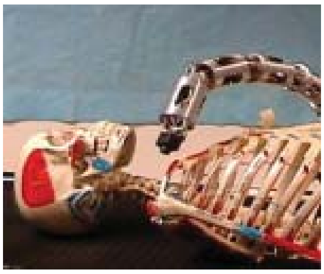
Map-less Navigation includes all systems which achieve navigation without making use of an internal environment representation. The robot's actions are determined by observing and extracting relevant information about the environment directly from the sensory perceptions. For example, a robot may simply follow another robot [Huber and Kortenkamp, 1995], or perform wall-following. Of the techniques that have been tried for map-less navigation, the prominent ones are behaviour-based [Nakamura and Asada, 1996], optical flow-based [Santos-Victor et al., 1993, Rizzi et al., 1998] and appearance-based approaches [Gaussier et al., 1997, Huber and Kortenkamp, 1995].

(a) NASA Rover Spirit on Mars.

(b) BigDog carrying goods in rough terrain.

(c) The robot OFRO on surveillance mission.

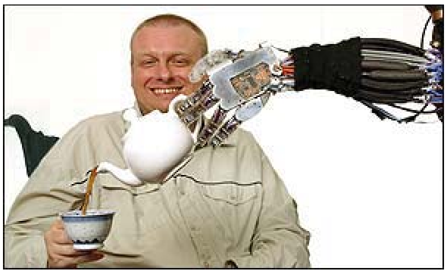
(d) KUKA robot in manufacturing.



(e) Snake-like robot examining a throat.

(f) Robotic lawn mower.

(g) Autonomous car Tartan Racer obeying real world traffic rules.



(h) Robot arm pouring a cup of tea for a disabled person.

(a) Photo courtesy NASA/JPL-Caltech,
(b) Photo from Boston Dynamics,
(c) Photo from http://www.msnbc.msn.com/id/13485246/ (31/03/2009),
(d) Photo from KUKA,
(e) Photo courtesy of the BioRobotics Lab, Carnegie Mellon University,
(f) Photo from Friendly Robotics,
(g) Photo from DARPA,
(h) Photo from http://news.bbc.co.uk/2/hi/health/2178226.stm (31/03/2009)

Figure 1.1: Application scenarios of today's robots.

When moving, the robot performs visual servoing towards the target. That is, the robot's actions are driven by the aim to gradually move into the direction which minimises the distance of the current observation and the goal position [Usher et al., 2003].

Map-free navigation is considered as short-range navigation in which a significant part of the scenery that is observable at the target position is also observable at the initial position and all positions along the planned path. Hence, the navigational freedom of a robot is limited and restricted to purely reactive behaviour.

Map-based Navigation assumes the robot is provided with a model of the environment. As long as the map is understandable to the robot, such a map may contain different degrees of detail, varying from complete *computer aided design* (CAD) models [Zhang et al., 2005] to a simple graph of relationships between the elements of the environment [DeSouza and Kak, 2002]. The robot uses sensor measurements to localise with respect to the map. The target position is also expressed with respect to the map. Based on the map, the most feasible trajectory between the current position and the target position can be planned.

In map-based navigation, the robot is provided with a map of the environment, for example from an external supervisor, so the freedom of the robot is limited to a predefined operational environment, specified through the map. Moreover, in unstructured environments it may be very difficult to create a map by hand or using CAD software.

Map-Building Navigation methods enable a robot to autonomously construct a model of the environment based on sensor readings and to use this map for navigation. Building a map from sensor data requires the extraction of data features and their combination to a suitable model of the environment which needs to be stored.

Maps are build either off-line following an exploration run, or incrementally while exploring the environment. The process of building a map which is simultaneously used for localising the agent is known as *Simultaneous Localisation And Mapping (SLAM)*.

1.3 Navigation Strategies of Humans and Animals

Autonomous mobile robots face similar challenges of navigation as human beings or animals experience. As humans and animals use their senses, robots use readings from different sensors to acquire information about the environment. Humans and animals compare current sensor readings with memorised data to localise themselves.

The long-distance navigational abilities of animals have fascinated humans for centuries and challenged scientists for decades. How is a bee able to return to its hive, an ant to navigate through the forest and a migratory bird able to circumnavigate the globe? In contrast to robots which work best in static environments, animals can handle highly dynamic surroundings. This ability is ascribed to the utilisation of different kinds of landmarks [Nehmzow, 1995, Nehmzow, 1999] which do not only comprise objects such as prominent trees, rocks and forest edges but also reference landmarks such as the sun, stars and magnetic senses [Wehner and Raeber, 1979, Waterman, 1988].

The desert ant (*Cataglyphis bicolor*) uses visual stimuli to identify a home location [Wehner and Raeber, 1979]. Experiments suggest that in order to move to a particular location ants try to match the current image with memorised snapshots. Close to the destination, they start searching for the nest in spiral-like motion patterns [Judd and Collett, 1998].

Amongst others, honey bees (*Apis mellifera*) orientate their flight path with the help of the sun [Wehner and Raeber, 1979] and use the polarisation of the sky. Furthermore, they stop their foraging if landmarks are intruded into or removed from their territory and conduct further orientation flights before continuing their flight [Waterman, 1988].

Planetarium experiments with birds (*Passerina cyanea*) have shown that they can use stars for navigation. If the artificial sky was shifted, their flight orientation changed accordingly [Waterman, 1988].

Further, many animals have specific sensing organs for navigation. For example bats or dolphins use a reliable sonar for navigation purposes [Altringham, 1998, Au and Moore, 1984].

Similarly, birds are able to reliably localise themselves and navigate over long distances in highly dynamic environments. The underlying principle for that ability is to memorise landmarks in the brain with a higher resolution near interesting locations [Nehmzow, 1999]. Furthermore, human beings and animals use multiple sources of perception to get information about the environment.

1.4 A Brief History of Robot Navigation

Robot navigation, that means localisation, mapping and path planning, has been researched for decades. Mobile robot navigation commenced in the 1950s with the installation of wire guided tractors in industrial factories [Dunkin, 1994]. This path following concept has been further developed by the 1970s where *autonomous guided vehicles (AGV)* navigated by following lines on the ground, such as painted stripes or even buried magnetic inductance wires [Tsumura, 1986]. Magnetic wires have the advantage of great reliability but suffer from inflexibility and substantial installation effort in the factories. Painted lines overcome these drawbacks but require permanent maintenance to ensure reliability. The major drawback of both methods is the restriction to fixed trajectories and paths so that the AGVs are inflexible and are limited to repetitive tasks.

A higher degree of flexibility was achieved via pose estimation through the introduction of artificial landmarks or beacons such as active infra-red [Giralt et al., 1979], active ultrasonic transducers [Kleeman, 1992], retro-reflective markers [Brady et al., 1988] or radar triheadrals [Durrant-Whyte, 1996]. Enabling the agent to estimate its position relative to the known beacon positions allowed easy redefinition of navigation paths without any changes to the physical environment. However, this method still requires specific infrastructural modifications to the environment, that is the placement of the beacons and an exact identification of the beacons positions.

The next step towards autonomous navigation was the use of the environment's structure to provide information instead of using artificial beacons which required modifications to the environment. The robot is given an accurate metric map, such as a layout of a floor, and the robot's sensory information is compared with the map for localisation. Metric maps were usually created using CAD models [Kent, 2000, Cox, 1991] or even by hand. While using the structure of the environment for localisation overcame the problem of installing artificial beacons, another problem was introduced: the problem of data association, that is the process of finding correspondences between elements of two data sets. For robot navigation, the data association problem concerns assigning sensory data to a given map. Using artificial landmarks, the data association problem can be easily avoided by attributing the beacons with unique identifiers such as bar-codes.