Abstract

Robots are rapidly evolving from factory work-horses to robot-companions. The future of robots, as our companions, is highly dependent on their abilities to understand, interpret and represent the environment in an efficient and consistent fashion, in a human compatible manner. The work presented here is oriented in this direction. It proposes a hierarchical probabilistic concept oriented representation of space that is based on typical household objects and structural elements such as doors (and walls). The primary contributions of this work are in the areas of representation and conceptualization for mobile robots; the key focus being, an increase in the semantic content of state-of-the-art mobile robot spatial representations and an increase in the spatial awareness (understanding) of a mobile robot about its surroundings. Thus, the theme of the work is - representation and conceptualization for spatial cognition in mobile robots. The work itself is holistic in that it also studies other related facets of the problem - these include perception and user studies (a cognitive validation of the thesis).

The single greatest challenge at the moment for mobile robotics is to endow a robot with the capacity to exhibit a greater degree of spatial awareness. The root-cause of the problem lies in the deficiency of semantic content in mobile robot representations. These two problems form the core motivations of this thesis. The problems are addressed in this thesis, using a two pronged strategy that focuses on (a) the representation of space and (b) the conceptualization of space. The objective in both cases is the same - the incorporation of a greater level of semantics in the representation and the endowment of a greater degree of spatial awareness for the mobile robot, while ensuring the human compatibility of the representation so formed.

The state-of-the-art in mobile robotics still relies on simple features such as lines and corners for mapping the environment. This work advocates an object based representation of space. This is not only motivated by intuition but also supported by user studies conducted as a part of this work. An extended (over several places) relative metric representation encoding objects and relationships between them is proposed in this thesis. The representation may also be interpreted as a global topological representation with local relative metric maps (object graphs) representing the individual places. Relationships are encoded as relative geometric information between the objects in order to keep the approach grounded in the state-of-the-art in mobile robotics research. Concepts (semantic and spatial) are incorporated in the representation, so as to enrich it in terms of semantics. The entire representation is probabilistic with appropriate measures of uncertainty being used for every encoded quantity.

This thesis further addresses the semantics problem in mobile robotics by proposing algorithms that enable the robot to conceptualize and cognize its surroundings. Specifically, this

work details efforts taken towards learning and generating concepts and attempts to classify places using the semantics (concepts) gleaned. Several algorithms, from naive ones using only object category presence to more sophisticated ones using both objects and relationships, are proposed. All proposed conceptualization methods are firmly grounded on the robot mapping basis created above in that both learning and inference use the information encoded in the underlying representation - objects and relative spatial information between them. The approaches are based on learning from exemplars, clustering and the use of Bayesian network classifiers. The approaches are generative. Further, even though they are based on learning from exemplars, they are not ontology specific; i.e. they do not assume the use of any specific ontology. The best two approaches are further studied in detail to understand their generalization capabilities. The presented algorithms rely on a robot's inherent high-level feature extraction capability (object recognition and structural element extraction) to actually form concept models and infer their presence during exploration. Thus, this thesis also presents methods that could enable a robot to to link sensory information to increasingly abstract concepts (spatial constructs).

To realize, support and strengthen this thesis, the facets of perception and user studies are also dealt with within the context of the problem. A broad overview of the state-of-the-art in object perception methods has been provided and studies have been conducted to evaluate local and global object recognition methods. Extensive and large scale (52 people) user studies have been conducted in an attempt to support this thesis, from a cognitive or human-robot interaction viewpoint. While the studies provide some interesting results, they also provide an empirical basis for many intuition inspired assumptions in works of science and engineering such as this one. Results of these studies broadly validate all aspects of the representation proposed in this work.

The outcome of all of these efforts is a hierarchical probabilistic concept-oriented representation of space. Such a representation would be useful for enabling robots to be cognizant of their surroundings and yet compatible with their human users. The robot would be endowed with a capacity to reason about spatial semantics and act in a semantically and potentially socially intelligent manner. From an application point-of-view, this thesis makes a contribution towards bringing robots into our homes, as our companions. From a scientific standpoint, the thesis makes a contribution in extending the state-of-the-art in mobile robotics by attempting to bridge the gap between the situated world (Robotics, in its current state) and the purely symbolic world (traditional AI).