Spatial Cognition for Mobile Robots : A Hierarchical Probabilistic Concept-Oriented Representation of Space

Shrihari Vasudevan

1. Introduction
   - Scientific Challenges:
     - Developing a scalable representation that is multi-modal and multi-purpose.
     - Addressing the lack of semantics / spatial-awareness problems in mobile robotics.
   - Structure of Report
     - Check figure 1.4
2. Perception
   - Not a thrust of thesis but critical to real world realization. Thus, an extensive review of different approaches is provided. Attempt to provide a good basis for future researchers in my area.
     - Introduction and review of state-of-the-art approaches. Includes my attempts + some others in same category of approaches + some that I am aware of.
   - Object perception - classification, recognition and detection.
   - Spectrum of approaches towards object perception - from local to global
   - Brief overview of different approaches in taxonomy.
   - SIFT object recognition in detail.
   - Evaluation
     - Global feature approaches - results from SPIE05 paper with simple single colored objects.
     - Local feature approaches - not a general evaluation of SIFT but rather of the system that has been used in this work (designed to be conservative and strongly reject false positives).
     - Results (numbers) from the global feature approaches might look nicer but
       - the SIFT approach doesn't have any requirements (other than texture) of simple single colored objects etc. Its thus much more versatile. Its also more robust to occlusions and reliable (illumination changes etc.).
       - The tests for the local features approach was more rigorous incorporating typical challenges of vision systems in mobile robotics such as blur, varying illuminations etc.
   - Local feature evaluation dataset (ASL OR Dataset) and SIFT OR code (ASL ORTK) have been made public !
3. Representation
   - Describes related work in the field of robot mapping and highlights key problems (motivation)
     - No semantics.
     - Modest spatial awareness.
   - Approach (LNAI07)
     - Uses results from user Studies to provide a cognitive basis to the approach. (ICRA07-SIR & 2008submitted)
     - Discusses the need for a metric basis for the representation (SPIE05 paper on OGM).
     - Describes the POGM (probabilistic object graph model). (ICIA06, IROS06-FS2HSC & RAS07)
     - Discusses the need for conceptualization. Introduces concepts building on the base representation to develop the representation sought in the thesis. (RAS08)
   - Explains mapping process
   - Real robot experiments corresponding to presented approach, described in chapter 5 (as methods from chapter:Perception and chapter:Cognition are also used)
4. Cognition

- Introduces the problems of conceptualization and place-classification. Clearly explains that the approaches presented are grounded in the underlying representation. Basically, the RAS08 paper.
- Discusses 4 approaches (refer figure 4.2) - M1 (RAS07) and M2 (IROS07) in brief (evaluation = cite paper). M3 (ECMR07) and M4 (IROS07-FS2HSC & RAS08) are first individually evaluated and then compared in detail through extensive cross validation tests. Preliminary results on extensions (directional relations) also given.
- Also provides experiments to understand why clustering using the concept models is better than using distance only.
- All approaches are based on learning from exemplars, clustering and Bayesian Network classifiers (specifically, the Naive Bayes Classifier) and implemented using a sound Bayesian Programming methodology.
- Details of dataset used also put up in appendix.

5. Experiments
   - Two kinds of real robot experiments corresponding to approach presented in chapter 3 (Representation)in addition to discussion of the approach / future work.
   - From objects to places (RAS07)
     - Gives the overall picture of how a probabilistic object graph based representation of space can be built over several places.
     - Outcome = an extended (over several places) relative metric representation of the space. Topology is implicitly encoded and hence the representation can also be interpreted as a global topological map of local metric maps.
   - From objects to **concepts** to places (RAS08)
     - Describes how semantics can be incorporated within the probabilistic object graph based representation of a place. Uses an office and a kitchen as examples. Movies provided for both cases.
6. User Studies
   - A cognitive validation to the representation proposed. (ICRA07-SIR & 2008submitted)
   - The related work of this chapter supplements that of the representation chapter in that this chapter also talks about Human-Robot Interaction (HRI) and how my approach is different from other approaches. *Spatial and Social awareness* are discussed in this context.
   - 52 person user study questioning subjects on a variety of issues pertaining to spatial cognition, while giving them a tour of the lab. The study analyzed, categorized and inferred from their replies.
   - Issues included
     - representation and description of objects and places, categorization of space, description of scenes, change of place etc.
   - Results broadly validated the approach. Some issues need to be differently addressed and some others were found out as a result of the study itself. Results also provide an empirical basis for intuition inspired assumptions.
7. Contributions
   - A hierarchical probabilistic concept oriented representation of space for mobile robots
   - Generative Bayesian algorithms for conceptualization and place classification
8. Other salient aspects / applications discussed in thesis (pointed out in different parts of the report)
   - Spatial and Social awareness in mobile robots (chapter: User Study & chapter: Conclusions)
   - Towards a new kind of Hierarchical (Semantic - Topological - Metric) SLAM (chapter: Experiments & chapter: Conclusions)
   - Holistic approach addressing problem - apart from main work, problems of perception and user studies are also addressed. (Thesis)
   - Clear methodology to map sensory information to increasingly abstract concepts (chapter: Cognition & chapter: Representation)
   - Increase in semantic content of mobile robot representations. (chapter: Representation)
   - Increase in spatial awareness of mobile robots (chapter: Cognition)
   - Ability to go beyond navigation/SLAM related problems and towards interaction and reasoning (Thesis)
   - Application Outcome - towards bringing robots into our homes (Thesis)
   - Scientific Outcome - towards bridging symbolic AI and Robotics (Thesis)