SPATIAL SEMANTIC HIERARCHY FRAMEWORK FOR VACUUMING ROBOTS

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Developing an autonomous intelligent vacuuming robot for household floors is not an easy task. The function of an autonomous vacuuming robot can be simply stated as to autonomously vacuum household floors while interacting appropriately with things one normally expects to find on floor such as furnitures, pets, trash, etc. However, underlying this simple job description are its numerous tough job requirements.

The world in which the robot is to function can be dynamic in different time scales. The robot has to avoid fast moving living beings such as pedestrians and pets. It also has to cope with slow changes of the world such as those produced by the repositioning of furnitures and the changing state (closing and opening) of doors. The state of doors really matters especially when the robot is supposed to vacuum the floor of several interconnected rooms.

The robot should know how to deal with a wide range of types of objects. Some objects should be recognized as objects to be vacuumed (e.g. small trash) while some as obstacles to be avoided and thus not vacuumed (e.g. furnitures and vacuumable but fragile objects). This requires advanced sensing capability for the robot to sense objects and their properties that are relevant and important (e.g. fragility) to distinguish objects to be vacuumed from those that are not to be vacuumed.

The robot should be efficient enough not to miss vacuumable spots. It should also be efficient with respect to certain cost functions such as power consumption and time requirement. A vacuuming robot should be able to improve its job performance through experience. It is not too unreasonable to hope for an intelligent vacuuming robot that can home in to a charging station for recharging when recharging is needed or to a trash depository where trash collected can be discharged into.

It is debatable whether a vacuuming robot can perform its task with a high level of efficiency without using an explicit (internal) model (e.g. map) of the floor but this issue will not be dealt with in this paper. This paper assumes that an efficient intelligent vacuuming robot needs to have an internal spatial representation which can be used for path planning and navigation (including homing) to maximize efficiency and to ensure reasonable floor coverage (i.e. minimal dirty vacuumable spots), and for supporting learning through experience to improve job performance.

In view of the above vacuuming robot functional requirements, the *Spatial Semantic Hierarchy* (SSH) approach [Kuipers and Byun, 1988] [Kuipers and Levitt, 1988] [Kuipers *et al.*, 1993] provides a good framework for developing a vacuuming robot. The SSH multileveled spatial representation has been demonstrated to successfully support a robust qualitative approach to robot exploration, mapping and navigation by Kuipers and Byun [1988] with experiments with simulated robot. Work is in progress to extend the SSH approach and to demonstrate a real functioning SSH robot in a real dynamic indoor environment. So far, the SSH approach has been successfully applied on a real robot to perform exploration, mapping and navigation in a simple static real environment.

Several issues and extensions to the SSH approach need to be addressed before we can expect to have a real functioning SSH vacuuming robot which is capable of learning a multileveled spatial representation of its working space and of using the knowledge embodied in each of these levels to provide different forms of support towards efficient execution of the vacuuming task. The control level is expected to manage the tactical requirements of real time obstacle avoidance and of coping capability with unexpected changes in the world. The existing local control laws including the reactive avoidance control law have to be changed, and the repertoire of local control laws has to be increased in order to cope with a wider range of objects. The issue on providing proper sensors and effectively using them to sense objects of wide range and their properties that are important in determining if objects encountered are vacuumable or to be vacuumed, is by itself an open robot sensing research problem which we are not pursuing. However, we do focus on extending the SSH approach to a working version that can cope with slow changes in the real world, especially with changes that can greatly affect the topological nature of the world (e.g. state of doors).

The topological map together with the metrical map within the SSH approach supports straighforwardly an efficient path planning capability which can be used to ensure efficient performance of the robot. With the current form of the SSH approach, a SSH robot avoids exploration into central region of large open spaces. This may not be a serious problem to a SSH vacuuming robot. Assuming that there are sufficiently many distinctive places on the boundary of the open spaces, and that the robot has reasonably reliable dead reckoning system, after an initial mapping process, the robot can venture to traverse across large open spaces without much worry of getting lost.

The SSH approach supports easily the registration of functionally important places such as the charging stations and the trash depositories into the spatial knowledge of the robot. If the robot has sufficiently rich sensing capability to define distinctive places that coincide spatially with the important places, the important places can be registered into the spatial knowledge of the robot by initially being discovered as distinctive places through the mapping process, and by annotating those distinctive places in both the metrical and topological map as the functionally important places by the user. If an important place does not coincide with any self-learned distinctive places of the robot, it can still be easily registered into the spatial knowledge of the robot by explicitly annotating the metrical map of the robot with its absolute (metrical) location. The robot may plan to arrive at that place by first performing some navigation to a distinctive place nearby the station, and by dead reckoning from the nearby place. With sufficiently many and well distributed distinctive places, navigation based solely on dead reckoning will be mostly over short distances and thus with small acceptable accumulated dead reckoning error.

References

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