A Natural Interface and Unified Skills for a Mobile Robot *

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Our research is aimed at developing an independent, cooperative, autonomous agent. Toward this end, we are working on two areas: a natural interface for interacting with the robot, and the basic underlying skills for navigating in previously unknown environments.

The interface we are developing combines natural language and gestures [1]. While human communication between individuals occurs on many channels, two of them, natural language and gesture, complement each other fairly regularly in daily communication. Since people interweave them freely during their interations, we assume they might readily do so in their interactions with a mobile robot.

Our interface allows the processing of complete or incomplete (fragmentary) commands. To process these types of commands, we keep track of the various goals during human-robot interactions by instantiating "context predicates," which are basically lists of the verbal predicates and their arguments expressed in logical form.

By utilizing context predicates, a discourse component of the interface tracks exactly which and to what extent each goal was achieved. With this information and by tracking goal achievement, the robot can continue to achieve unaccomplished goals on its own, no matter at what point or in what state the system is currently. Thus, context predicates permit the system to work independently on achieving previously stated, but as yet uncompleted, goals. This capability ultimately allows the user greater freedom to interact naturally without having to explicitly state or re-state each expected or desired action when an interruption occurs. We hope to extend goal tracking so that the mobile robot can complete semantically related goals which are not initially specified or which are unknown to the human at the time when the initial goal is instantiated.

This natural interface is currently in use with a mobile robot. Navigation goals and locations are specified by speech and/or with natural gestures. Commands can be interrupted and subsequently completed with fragmentary utterances.

To provide the basic underlying skills for navigating in previously unknown environments, we are working to create a mobile robot system that is robust and adaptive in rapidly changing environments. We view integration of these skills as a basic research issue, studying the combination of different, complementary capabilities. One principle that aids integration is the use of unifying representations which allow better communication and interaction among different components.

Our most recent work uses evidence grids as a common representation to integrate mobile robot exploration, localization, navigation, and planning [?]. In addition, this integrated system includes methods for adapting maps to allow for robust navigation in dynamic environments. As a result, a robot can enter an unknown environment, map it while remaining confident of its position, and robustly plan and navigate within the environment in real time.

We create two types of representations with the evidence grids: short-term perception maps, and long-term metric maps. The short-term maps store very recent sensor data that does not contain significant odometry error, and these maps can be used for obstacle avoidance and for localization. The long-term maps represent the environment over time, and can be used for navigation and path-planning.

The use of evidence grids requires that the robot be localized within its environment. To overcome odometric drift and errors, we have developed a method for *continuous localization*, in which the robot continually corrects its position estimates. Continuous localization builds the short-term perception maps, and at frequent intervals registers the oldest short-term map against the long-term map, locating the robot within

*This work was sponsored by the Office of Naval Research.

the environment.

In order for mobile robots to operate in unknown environments, they need the ability to explore and build maps that can be used for navigation. We have developed the *frontier-based exploration* strategy based on the concept of frontiers, regions on the boundary between open space and unexplored space. When a robot moves to a frontier, about half of its sensors can still see the old, known environment, which can be used by continuous localization to maintain accurate odometry. Its other sensors see into unexplored space and expand the map. By moving to successive frontiers, the robot can constantly increase its knowledge of the world. The new, expanded maps produced by the exploration are passed to continuous localization as its new long-term map.

After exploration is complete, changes in the world (blocked passages, moved obstacles, etc) must also be modeled. We have added a learning component to the continuous localization algorithm to allow the long-term map to be updated with recent sensor data from the short-term perception maps, making the long-term map adaptive to the environment.

In order to provide robust navigation, we have incorporated Trulla, a propagation-based path planner which uses a navigability grid to describe which areas in the environment are navigable (considering floor properties, obstacles, etc). In our system, we have integrated Trulla by replacing its navigability grid with our long-term metric map. As our long-term map adapts to changes in the environment, Trulla can replan using the robot's current knowledge about the world.

Continuous localization's long-term map update method can adapt to somewhat rapid and persistent changes in the environment, but not to very fast changes, such as a person walking through the room. Accordingly, paths generated by Trulla are not sufficient to prevent collisions with transient obstacles.

We have integrated the Vector Field Histogram (VFH) reactive navigation method to avoid transient obstacles that are not yet represented in the evidence grid. VFH uses an HIMM occupancy grid to model the robot's immediate surroundings. In our integration, we replace the HIMM occupancy grid with the short-term perception map produced by continuous localization. The short-term perception map allows VFH to consider all sensors, and yields a less noisy picture of the robot's immediate environment. Fig. 1 illustrates the complete architecture.

When heading into an unknown environment, the robot autonomously maps the environment while maintaining accurate odometry, producing the initial long-term map. Each new short-term perception map long-term map is sent to a Map Server process which in turn makes the sensor-fused perceptions of the environment available to the various processes.

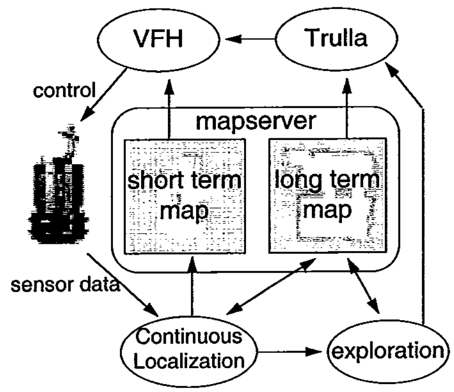

Figure 1: Architecture of integrated system

After exploration, the user specifies a navigation goal to Trulla, which consults the Map Server for the current long-term map and computes the vector field describing the best path from each cell to the goal. Trulla sends the vector field to VFH, which uses the robot's current position to index the vector field and get the direction to the goal. VFH retrieves the short-term map from the Map Server, and steers the robot in the direction closest to that which was planned by Trulla.

While VFH is steering the robot, continuous localization continues to correct odometry and produce short-term and adapted long-term maps. With each new long-term map, Trulla replans and sends a new vector field to VFH which uses it for subsequent navigation.

References

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