A cartographer robot: merging and interpreting maps in unknown environments

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ABSTRACT
The ability to navigate is a fundamental issue both in animal and in mobile artificial systems. The problems of map building and path-planning constitute sub-goals aiming to the optimization of the trajectories followed in order to reach a positional goal. Present work deals with the problem of map generation and interpretation by an autonomous robot while performing a contour following navigation strategy. A fuzzy logic based approach has been used to map ultrasonic sensor readings to objects (obstacles). This ultrasonic based representation of the environment is reinforced by means of the infrared sensor readings in order to fix objects' discontinuities. Finally some spatial reasoning, based on expert knowledge, is performed on the obstacles/maps in order to get a more refined representation of the perceived world.

1. INTRODUCTION

For both animals and mobile robots, the ability to self-localize and plan paths, or what is known as navigation, is of utmost importance. A navigation system requires not only reactive behavior, but also the ability to interpret sensory information with respect to global goals, intelligent interaction with the environment (e.g. active sensing), and recovery from errors. Navigation is therefore an ideal test bed for investigating theories of intelligent behavior [Mataric94]. Present work deals with the navigation and interpretation tasks needed to build maps of unknown environments. Such maps will be further on used to allow and optimize global navigation tasks based on the approximate map, on topological relations and on low level fuzzy reactive behaviors [Garcia-Alegre93]. To accomplish the cartographer task the robot has first to be able to navigate in the most appropriate way to collect relevant information from the environment. Therefore a pilot_follow_contour strategy has been designed to safely navigate as close as possible to the different edges that conform an office environment. Then the echo points cloud is translated to a geometric representation based on a fuzzy logic approach [Gasos96a], that is finally refined in an incremental way by means either of infrared sensors readings or successive runs.

2. THE CARTOGRAPHER ROBOT DESCRIPTION

The system in charge of such task is a mobile robot B21-Hermes, Figure 1, that it is presently endowed of a belt of 24 ultrasonic sensors at 77cm. height, 3 belts of infrared sensors: 24 at 48cm., 24 at 10cm., and 8 looking downward and 56 pressure sensitive switches mounted behind 360º outer upper and down panels. The actuators are four engines that act on four wheels performing synchronous drive and steering. All sensing and acting is supported by an on-board computer PC486/66 running under Linux operating system. It has a distributed architecture of processors to filter, calibrate, and preprocess the raw data as well as to convert translational and rotational commands in motor voltages.

3. THE REACTIVE AND PILOTING LEVEL

The behavior of the robot to safely navigate through its environment and meanwhile collecting the information needed to built the map, is framed in a Hierarchical Multi-Agents Architecture [Garcia-Alegre95]. The first level allows a reactive locomotion that is conformed by three Basic Behaviors, designed to face increasing degree of emergency: FORWARD, AVOID and STOP&BACK.

- **FORWARD** is based on ultrasonic echoes readings and it is activated by upper level agents. It triggers its behavior when free_space in the direction of the previously selected goal is perceived, then it generates a movement with such a heading at a particular speed that depends on internal and external conditions.
- **AVOID** is also based on ultrasonic sensors and it is activated by upper level agents. Its behavior is triggered when it perceives a frontal obstacle in a wide angle, then it generates a detour movement if the safety_distance is surpassed. Changing this safety_distance parameter the robot shows a variety of avoidance trajectories that can be associated to a more o less cautious behavior.

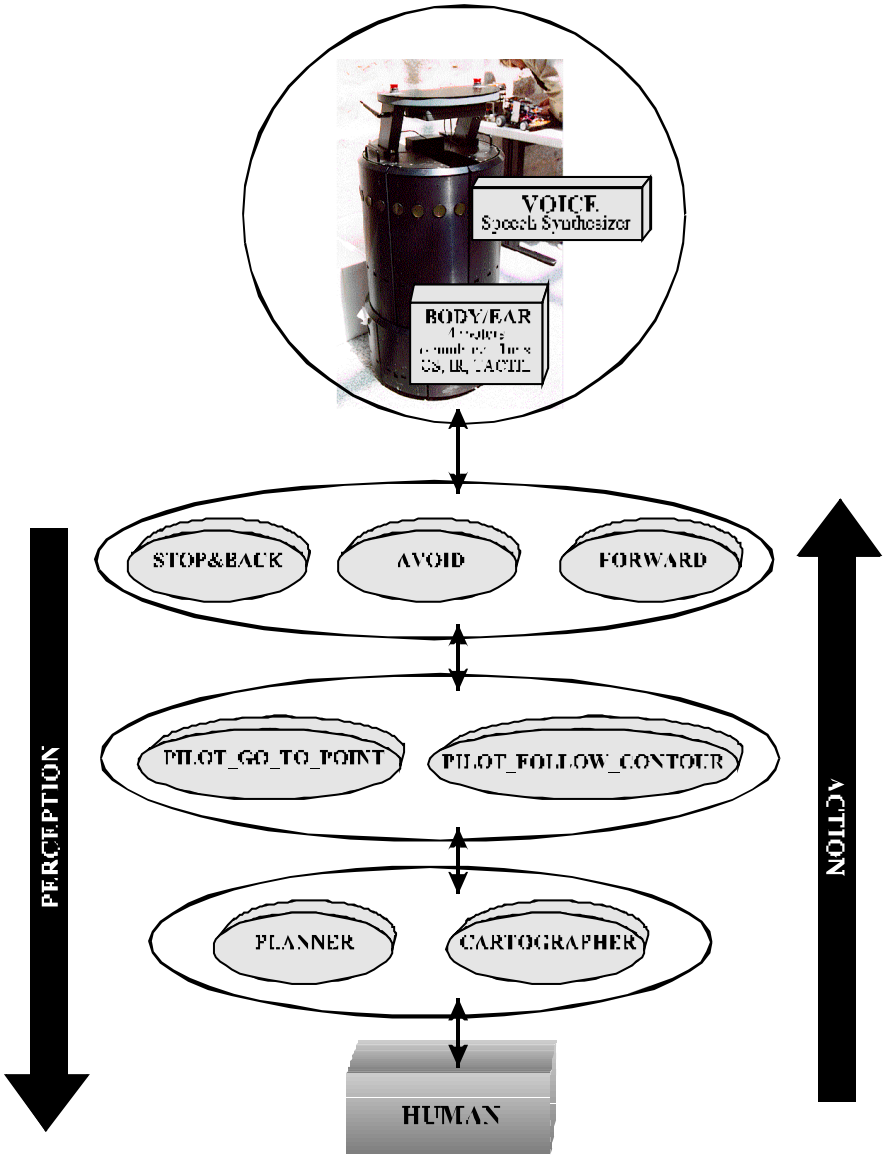


Figure 1: The Hierarchical Multi-Agent Architecture

- **STOP&BACK** is driven by the tactile and infrared sensors readings and it is required to recover from unexpected events due to ultrasonic sensors failures, to very fast obstacles, or to very acute obstacle shapes.

These Agents are modeled as fuzzy knowledge bases [Garcia-Rosa90] that decide on the next robot heading angle and speed at a rate of two hundred milliseconds, having as inputs the current ultrasonic, infrared, tactile and proprioceptive sensors values. Any possible situation not accounted for in the three Basic Locomotion Behaviors generates a STOP default action. Reflected infrared intensity, distance, orientation and proprioceptive variables as speed, odometric position, and battery voltage are represented as fuzzy sets and are defined through trapezoidal membership functions. Instantaneous values of these variables for all sensors constitute the representation space of this reflex or reactive level.

The appearance of more than one desirable and possible Behaviors at the reactive level causes the emergence of higher level Behaviors that coordinate through simple rules the action selection for identical sensory information [Gacia-Alegre97 and Mataric92]. This is the reason of the emergence of a second level, on top of the reactive levels, hereafter called the piloting level. At this level are located those navigation strategies addressed to reach or to maintain a relative position between the robot and the world as those encapsulated on the Behaviors: PILOT_GO_TO_POINT and PILOT_FOLLOW_CONTOUR.

These Behaviors have a temporal and spatial window of a few seconds and do not care on the specific details that are contemplated by the low-level behaviors. The representation of the perception and actions at this level is more abstract and deals with terms such as: {min_front_distance, min_right_distance, relative_orientation, wall_angle, expected_wall_direction} and {forward, avoid, stop&back}.

4. MAPS GENERATION: A FUZZY APPROACH

Map building is one of the possible robot activities to be performed within an indoor environment. This ability if performed autonomously by robots, would greatly help human being in such a repetitive and time-consuming task. Maps also allow for a time minimalist navigation [Guinea97], e.g. between offices in order to deliver either equipment or documentation. Maps are useful, in addition to optimal path planning for robot self-localization and for expectations generation on the robot trajectory [Crowley85].

To provide information on the indoor environment ultrasonic range finders have been selected as a fast and easy sensor to build world models. Most maps building techniques deal with this problem based upon a probabilistic approach on an occupancy grid model [Elfes87, Moravec88, Drumheller87, Zelinsky91, and Thrun96]. These approaches gather information about the relative frequencies and express uncertainty as the probability that an object occupies a given cell. Interesting methods for uncertainty representation based on fuzzy logic have also been developed [Saffiotti96, Polini95]

As boundary extraction from sensor observations is a process that works with inaccurate and noisy data, a fuzzy approach has been used. Thus, fuzzy sets represent the uncertainty in the real location of the object boundaries and the degree of membership to a fuzzy set expresses both this uncertainty and the degree of similarity when compared with neighbors' boundaries. This approach propagates the uncertainty from the raw measurements to the location, orientation and size of the boundaries.

This fuzzy approach generates from a discrete set of points a set of rectangles, namely basic segments, proceeding with the following operations' sequence [Gasos96b]:

- Processing of raw ultrasonic data to eliminate clear misreading
- Grouping of consecutive sensor measurement from the same object- side
- Fitting points to a straight line whose uncertainty at the middle position and orientation are represented by means of fuzzy sets
- Clustering of basic segments of the same object-side coming from both different sensors and different robot positions, to derive a single object boundary [Maio96].
- Finally, analysis of the connectivity between pairs of fuzzy boundaries and reconstruction of the envelope of the environment

The uncertainty propagates to the subsequent steps involved in map building to obtain both a plausible spatial frame of the environment and its degree of confidence. The degree of uncertainty in the location of a basic segment is affected by: 1) The lack of knowledge on the echo conditions (sensor-object orientation, and object texture and shape), 2) Distance between sensor and object and air conditions and, finally 3) Dead reckoning estimation of the robot location (error increases with traveled distance and heading changes). In Figure 2, it is displayed a cloud of points corresponding to the sensed objects, the real trajectory, and the computed segments' map.

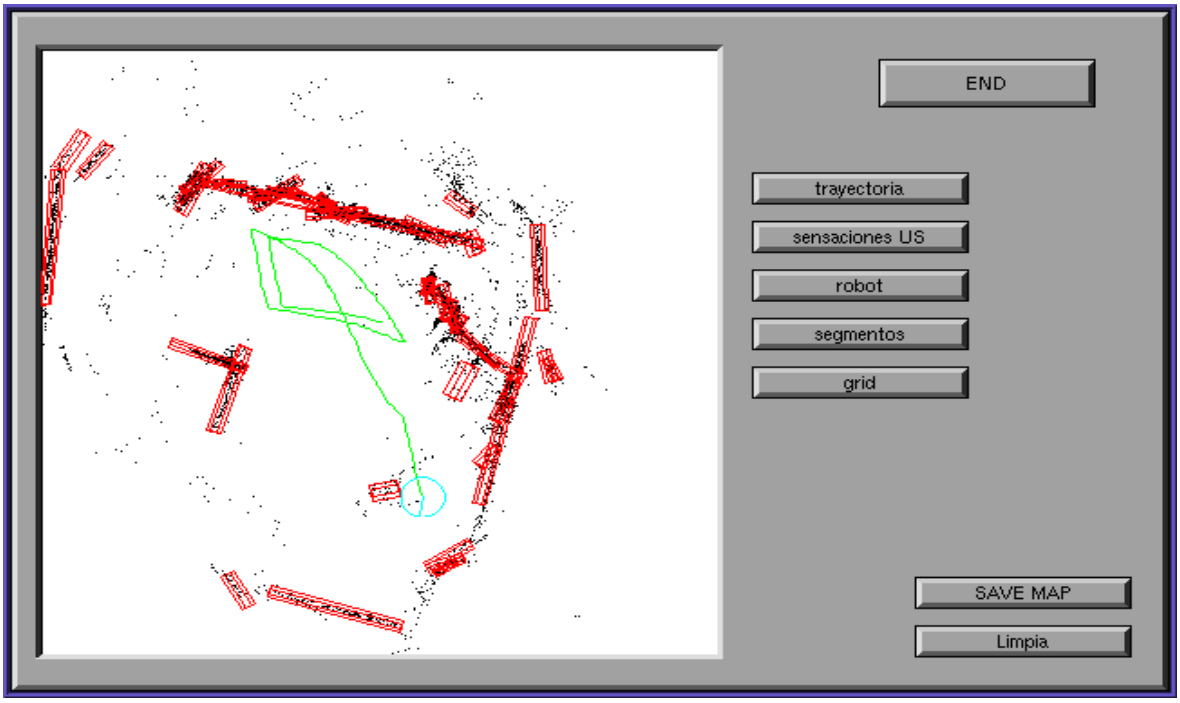


Figure 2: Ultrasonic sensor readings, real robot trajectory, and segments' map.

5. SOME HEURISTICS TO OPTIMIZE THE MAP

The fusion procedure by which segments' map emerges is based only in geometrical relationship between points and segments that are obtained only by means of ultrasonic sensor readings. In accordance with [Flynn 88], we improve the map discontinuities using infrared sensor readings and also expert knowledge on the real environment. Both are used to discover some architectonic structures by reinforcement of the ultrasonic readings. In an office environment the more relevant cues from a navigational point of view are the doorways and concave and convex corners. Based upon former premises, a knowledge based approach is suggested for both map completion and map improvement, that analyzes: 1) relations among segments in order to get a clearer map and 2) sensors readings to locate natural structures on the map.

A knowledge base is proposed for the incremental improvement of the map as obtained in an initial robot run. Some examples of the heuristics that are been used are:

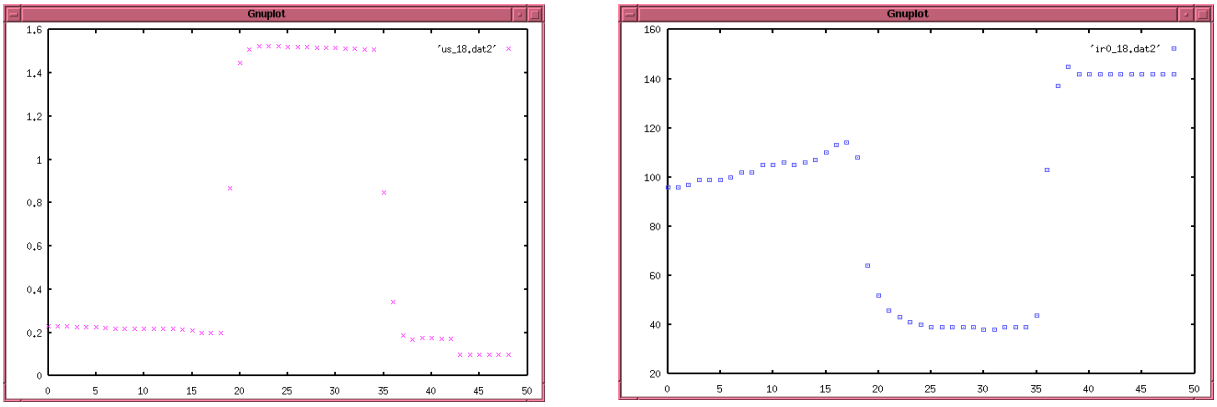
RULE1:
IF **DIFERENCE_ENERGY (IR(t)-IR(t-1)** is **BIG_POSITIVE**
THEN Possible_hole = TRUE
Initiate_clock

RULE2:
IF **DIFERENCE_ENERGY (IR(t)-IR(t-1)** is **BIG_NEGATIVE**
AND Possible_hole = TRUE
THEN hole = TRUE
End_clock
Possible_hole = FALSE
Average_Width_hole = time_interval * average_speed

RULE3:
IF **INTERSECTION_AREA (Segment$_{n1}$, Segment$_{n2}$)** is **BIG**
AND **DIFERENCE_ANGLE (Segment$_{n1}$, Segment$_{n2}$)** is **SMALL**
THEN Delete the smallest segment

RULE4:
IF **COLLINEAR (Segment$_{n1}$, Segment$_{n2}$)** is **HIGH**
AND **SEPARATION(Segment$_{n1}$, Segment$_{n2}$)** is **SMALL**
AND hole = FALSE
THEN Segment_new = Segment$_{n1}$ $\cup$ Segment$_{n2}$
Delete (Segment$_{n1}$)
Delete (Segment$_{n2}$)

Where DIFERENCE_ANGLE, DIFERENCE_ENERGY, INTERSECTION_AREA, COLLINEAR, and SEPARATION are considered as fuzzy variables. First rules are only applied to the lateral infrared sensors (IR) aligned to the wall in a pilot_follow_contour strategy. Rule3 implicitly correspond to a segments subsumption strategy. The segments union operation, in Rule4, behaves much like that defined in [Gasos96b]. In Figure 3 are displayed the distance variations of a lateral ultrasonic sensor and the energy variations of the corresponding infrared sensor, when the robot moves in parallel to an open door using the pilot_follow_wall strategy activated by the cartographer.



(a) **(b)**

Figure 3: (a) Distance variations from a lateral ultrasonic sensor. (b) Infrared intensity variations from a lateral infrared sensor.

6. COMMENTS, CONCLUSIONS AND FUTURE WORK

The fuzzy approach is a flexible and easy approach for building approximate maps. Ultrasonic sensors have proved to be reliable enough for the purpose of building the first version of a map that aims to be incrementally improved by means of: infrared sensor readings, ultrasonic measurements in different robot runs and expert knowledge on the application domain. While ultrasonic sensors are good for distances in medium and large range distances, infrared reflected intensity readings constitute a complementary help for short range distances in detecting angular variations, but being too much sensitive to objects color and environment illumination changes they are not recommended for building maps.

Future work in map building will be devoted to heuristically improve an approximate map as well as to the fusion of maps from different areas in order to get a floor map of a building. Then these fused maps obtained with the cartographer abilities are been used as the world model for a path-planner that aims the generation of optimum paths guided by a heuristic.

7. ACKNOWLEGMENTS

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