High-Level Multisensor Integration

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Abstract

In this paper we describe an approach to high-level multisensor integration in the context of an autonomous mobile robot. Previous papers have described the development of the INRIA mobile robot subsystems:

1. **sensor and actuator systems**
2. **distance and range analysis**
3. **feature extraction and segmentation**
4. **motion detection**
5. **uncertainty management**, and
6. **3-D environment descriptions**.

We describe here an approach to:

- the **semantic analysis** of the 3-D environment descriptions.

This analysis is organized in terms of robot goals and behaviors. This is accomplished by the use of logical behaviors. Such an approach allows for active control of the sensors in acquiring information.

1 Introduction

Multisensor integration has received a good deal of attention in recent years due to the availability of sensors, actuators, and processors. Two major testbeds for such work are:

- robotic workcell automation, and
- mobile autonomous robots.

The first of these involves applying strong knowledge-based techniques to the manufacturing environment, while the second concerns integrating several levels of information processing into a single autonomous system. We restrict our attention here to the second problem.

Figure 1: Autonomous Robot Vehicle Research [figure missing]

Autonomous mobile robots have been studied in a wide range of contexts. Figure 1 imposes an organization on most of the typical keywords. Obviously, the problem of navigation is basic to mobile robots and consequently has been studied by many people on specific implementations [15, 24, 30]. Most such systems must use sensors (e.g., sonar or cameras [10, 29]) and actuators and must control them [9]. The use of sensors requires the study of uncertainty management [16] and multisensor integration [8, 18, 26]. More global approaches to the sensorimotor problem can be found in [1, 14], and special purpose architectures are being planned [2].

One level up, the mapping of procedural behaviors onto the sensorimotor control structure is of interest [3, 17, 22, 20, 21]. The world representations also exist at this level: both the metrological [5, 4], where precise measurement is paramount, and topological [6, 12, 13, 28], where adjacency relations are useful for path planning, etc. It is even possible to study primitive forms of learning in this context [28].

Broader studies are usually oriented towards particular applications (e.g., the nuclear industry, road following) or towards well-defined, but limited goals (e.g., indoor [7, 11] or outdoor [25] navigation).

Finally, the 'highest' level involves the specification and representation of the knowledge appropriate to a given task [23] and its compilation into executable robot behavior (or programs) [19]. The literature is quite large on most of these subjects, and these references are intended as representative of the work in this area. It should be pointed out that most system designers use a central balckboard and some form of direct production system or a compiled version (i.e., a decision tree) to represent knowledge.

From this short summary, it can be seen that the scope of autonomous robot research is indeed vast, but the difficult problems found here are yielding to the steady advance of technical and theoretical developments. In the remainder of this paper, we describe current work on the mobile autonomous robot at INRIA.

2 Problem Definition

We suppose that our mobile robot is wandering through an unknown indoor environment. The robot must:

- **incrementally build a 3-D representation of the world** (i.e., determine its motion and integrate distinct views into a coherent global view),
- **account for uncertainty in its description** (i.e., explicitly represent, manipulate and combine uncertainty), and
- **build a semantic representation of the world** (i.e., discover useful geometric or functional relations and and semantic entities).

In this paper we describe an approach to solving the third problem. (See [4] for details on efficient techniques for producing a local 3-D map from stereo vision and structure from motion as well as a method for combining several viewpoints into a single surface and volume representation of the environment and which accounts for uncertainty.)

Figure 2: (a) Semantic Net Defining World Model (b) With Robot [figure missing]

Figure 3: A Representation of the Command: “Go to the office door” [figure missing]

The mobile robot must use the 3-D representation to locate simple generic objects, such as doors and windows, and eventually more complicated objects like chairs, desks, file cabinets, etc. The robot can then demonstrate “intelligent” behavior such as going to a window, finding a door, etc. The representation should contain semantic labels (floor, walls, ceiling) and object descriptions (desks, doors, windows, etc.).

3 Logical Behaviors

The proposed approach is straightforward and exploits our previous work on logical sensors, the Multisensor Knowledge System, and multiple semantic constraints. The World Model is defined in terms of a semantic network (e.g., see Figure 2a). The nodes represent physical entities and the relations are (currently) geometric. “Behind” each node is a logical sensor which embodies a recognition strategy for that object. The relations are simply tabulated.

A goal for the robot is defined by adding a node representing the robot itself and relations are added as requirements (see Figure 2b). This method permits the system to focus on objects of interest and to exploit any strong knowledge that’s available for the task. The added relations are satisfied (usually) by the robot’s motion. Techniques for the satisfaction of the relations are called **logical behaviors**.

As an example, consider the world model in Figure 3 which represents a specific office at INRIA. The addition of the robot and the “Next_to” relation fires the “Find_door” logical sensor. This in turn causes the strategy for door finding to be invoked. Such a strategy may attempt shortcuts (quick image cues) or may cause a full 3-D representation to be built and analyzed. Logical behaviors are then the combined logical sensors and motion control required to satisfy the “Next_to” relation.

Note that it is in the context of such a strategy that high-level multisensor integration occurs in goal-directed behavior. We are currently implementing a testbed for experimentation.

4 Implementation

4.1 Mobile Robot

Figure 4 shows the operational mobile robot at INRIA. It is similar to other mobile robots (e.g., like those at CMU or Hilare at LAAS). Figure 5 shows the geometry of the robot (length: 1.025m, width: .7m, and height: .44m) and the locations of the sonar sensors. The two rear wheels drive the robot.

Figure 4: The INRIA Mobile Robot [figure missing]

Figure 5: The Geometry and Sensor Placement on the INRIA Mobile Robot [figure missing]

The onboard processing consists of two M68000 series microprocessors on a VME bus; one controls the sonar sensors, and the other runs the real-time operating system, Albatros. The two main wheels are controlled separately, and the system has an odometer.

A graphical interface has been developed which permits a model of the ground floor to be specified and for the robot to be instructed to move in that envirnoment while avoiding obstacles. For full details, see [27].

4.2 Building Environment Descriptions

Many papers have been published describing our methods for building robust environment descriptions [5, 4, 10, 11]. Current capabilities include 3-camera stereo and robust multi-view fusion.

We work on typical office scenes and reconstruct 3-D segments from such scenes. This 3-D description provides the basis for the development of logical sensors for object recognition and localization.

5 Summary and Future Work

High-level multisensor integration must be investigated in the context of real-world problems. We have described current work on an autonomous mobile vehicle under development at INRIA. We propose “logical behaviors” as an approach to robot goal representation and achievement.

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