

# An Integrated Navigation and Motion Control System for Autonomous Multisensory Mobile Robots

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*An essential task for a mobile robot system is navigation and motion control. The characteristics of perception required by environment modeling or motion control are very different. This may be basically obtained using several sensors. The described NMC system integrates the elementary data acquisition, modeling, planning, and motion control subsystems. A set of rules determines the dynamic structure and the behavior of the system and provides a man/machine and system to system interface.*

## 1 Introduction

Research on mobile robots began in the late sixties with the Stanford Research Institute's pioneering work. Two versions of SHAKEY, an autonomous mobile robot, were built in 1968 and 1971. The main purpose of this project was "to study processes for the real-time control of a robot system that interacts with a complex environment" (NIL 69). Indeed, mobile robots were and still are a very convenient and powerful support for research on artificial intelligence oriented robotics. They possess the capacity to provide a variety of problems at different levels of generality and difficulty in a large domain including perception, decision making, communication, etc., which all have to be considered within the scope of the specific constraints of robotics: on-line computing, cost considerations, operating ability, and reliability.

A second and quite different trend of research began around the same period. It was aimed at solving the problem of robot vehicle locomotion over rough terrain. The work focus was the design and the study of the kinematics and dynamics of multilegged robots (McG 79).

During the seventies various reasons, such as too remote real-world applications and lack of efficient on-board instrumentation (computers, sensors, etc.), slowed the research thrust in the field and even lead to important funding cuts. Meanwhile the so-called industrial robots, i.e., manipulator robots, became the main body of a fast expanding field of robotics.

The present renewal of interest in mobile robots started in the late seventies fostered by powerful on-board signal and data processing capacities offered by microprocessor technology.

Today, in 1983, the scientific reasons for using mobile robots as a support for concep-



tual and experimental work in advanced robotics hold more than ever. Furthermore a number of real-world applications can now be realistically envisioned, some for the near future. These applications range from intervention robots operating in hostile or extremely dangerous environments to day-to-day machines in highly automated factories using flexible manufacturing systems (FMS) technology.

In this paper we focus on aspects of the HILARE project's current research that we believe are the key to autonomous mobile robots development: system integration, multisensory driven navigation, and motion control.

## 2 Overview of HILARE, A Mobile Robot

The HILARE project started by the end of 1977 at LAAS <GIR 79>. The project's goal is to perform general research in robotics and robot perception and planning. A mobile robot was constructed to serve as an experimental means.

The environment domain considered is a world of a flat or near flat smooth floor with walls which include rooms, hallways, corridors, various portable objects, and mobile or fixed obstacles.

### 2.1 The Physical Infrastructure

The vehicle has three wheels as shown in figure 1. The two rear wheels are powered by stepping motors and the front wheel is free. This structure is simple but allows the robot to perform such trajectories as straight lines, circles and clothoids.

size = 1.10 x 1.10 x 0.70 m  
weight = 400 kg  
moving velocity = 1 m/sec max

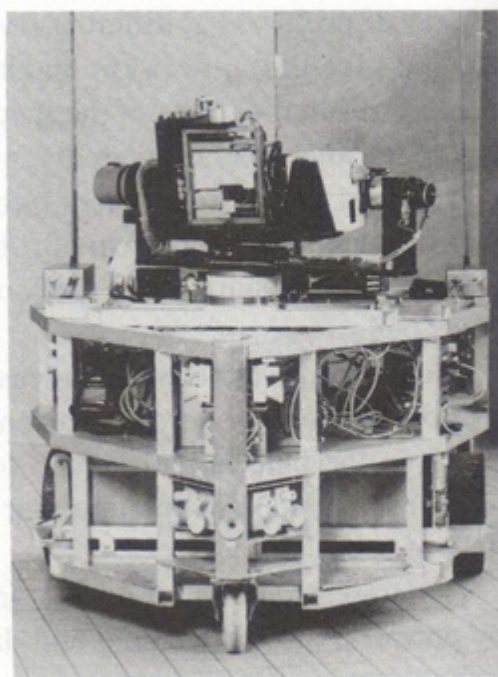
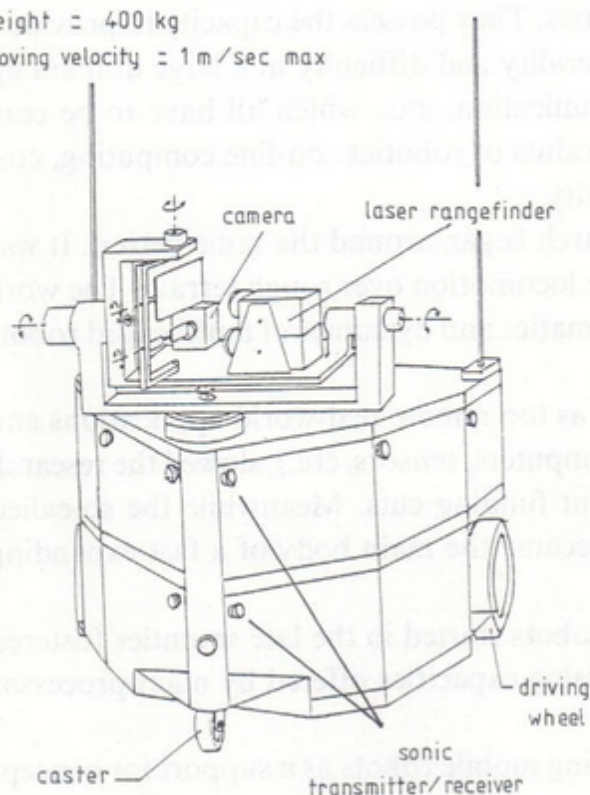
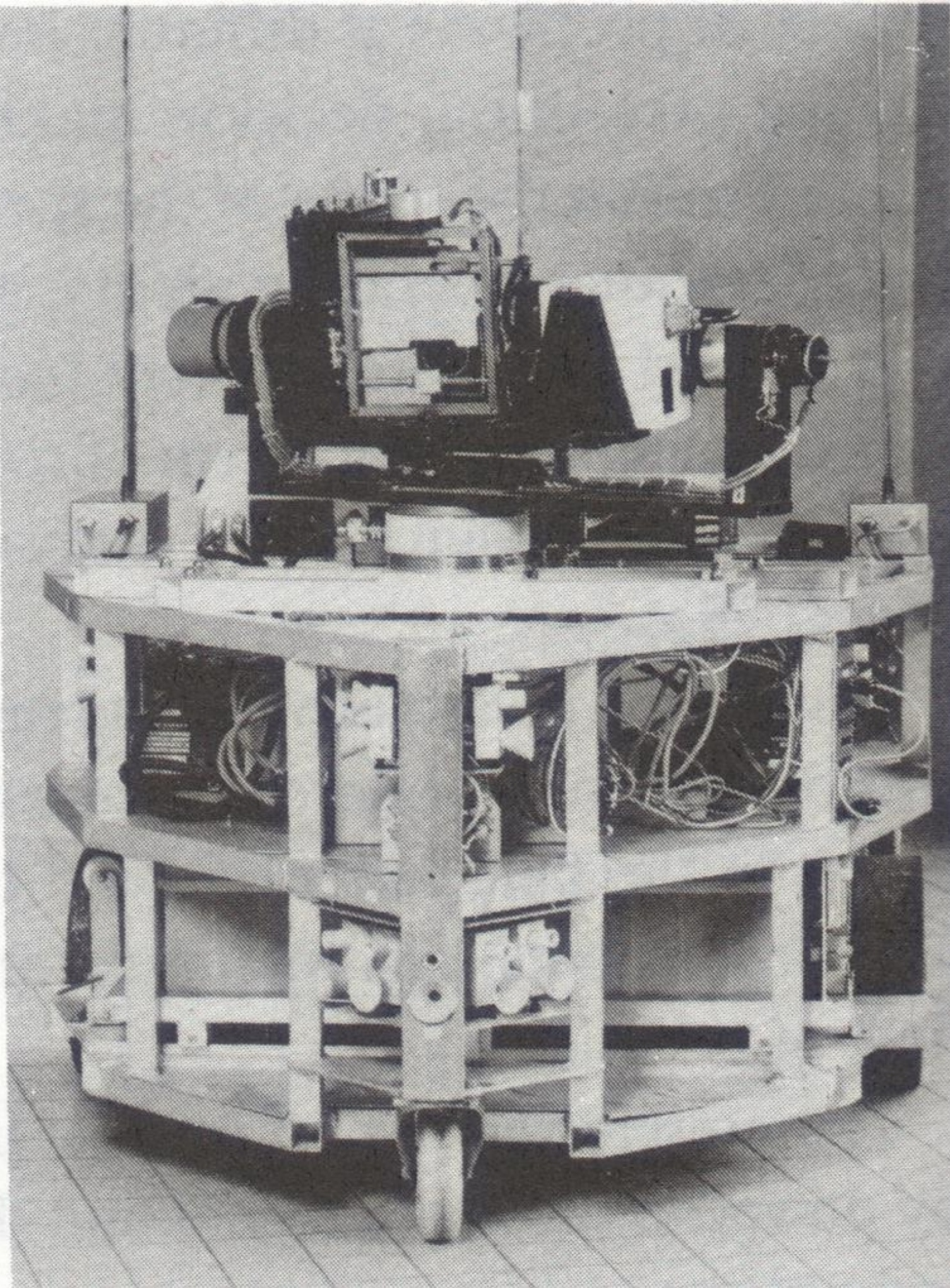


Figure 1



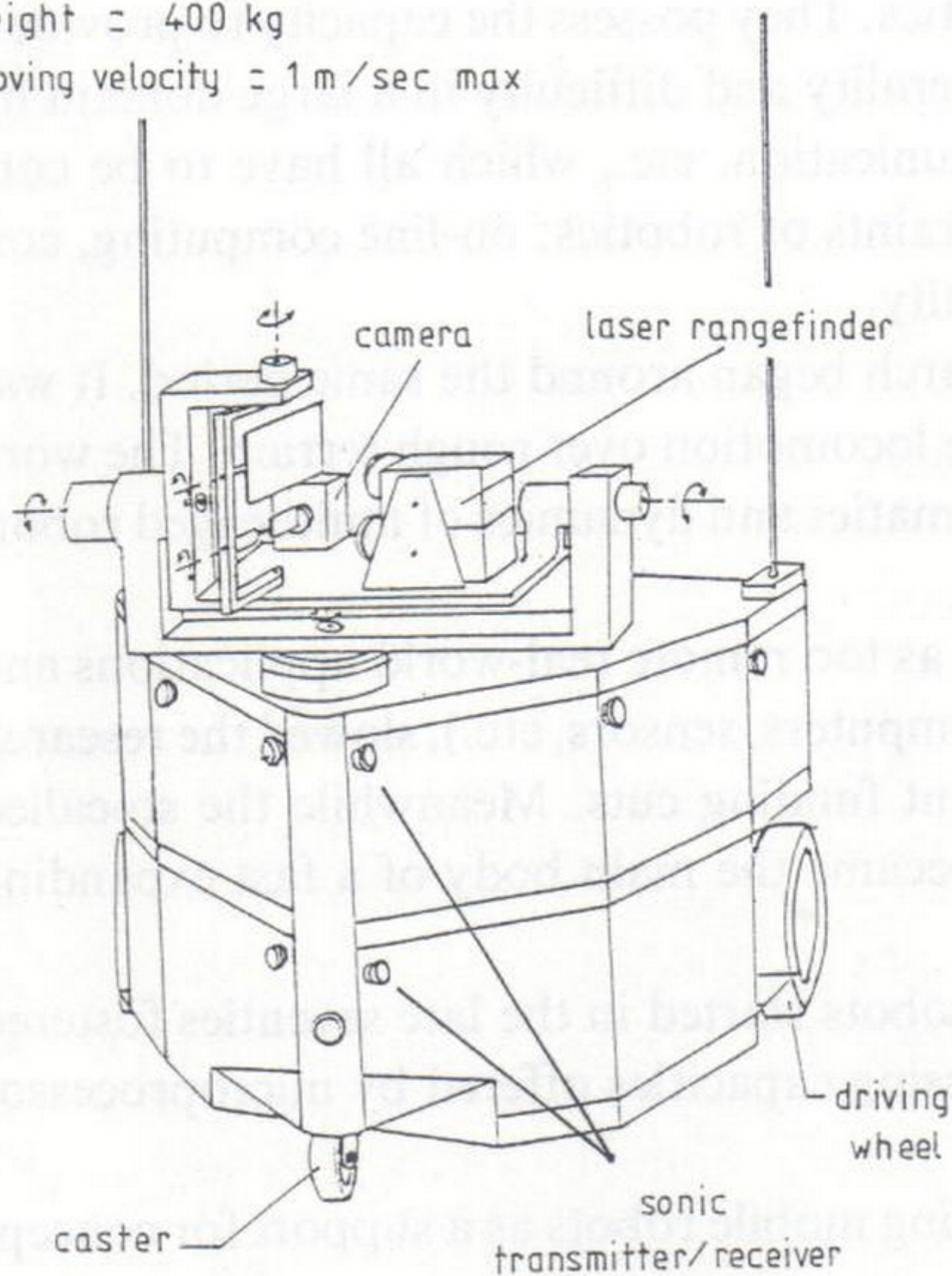




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The perception system is composed of two separate subsystems serving different purposes: an ultrasonic system and a vision-based system. To improve odometry path-control, two optical encoders are also used. A manipulator is to be put on the robot in the future. The computer system supporting the various robot functions has a distributed multilevel architecture (figure 2): several (currently six) robot-borne microprocessors are radio-linked to a 32-bit computer accessing one or more other larger or similar processors.

## **2.2 The Perception System**

A multisensory system provides the robot with the information it needs about its environment. The various sensors are used independently or in concert.

### *Ultrasonic Perception*

A set of 14 ultrasonic emitter-receivers distributed on the vehicle provides the range data up to 2 m. The system has two functions:

1. An alarm function that warns the robot of the near vicinity of some object. The reaction of the robot is usually to come to a full stop if moving, but in some circumstances it will try to avoid the detected object.
2. A closed-loop local obstacle avoidance function. In this mode the robot uses the range data to move along an object, maneuvering to stay at a fixed distance from its surface.

### *Vision*

A camera and a laser range-finder are the main perception system. They are mounted on a pan and tilt platform. The laser can be used in scanning mode, or it can measure ranges within the camera's field using a retractable mirror. This provides the robot with 3-D data about its environment <FER 82>.

### *Position Referencing*

HILARE's position can be obtained either relatively to objects and specific environment patterns or in a constructed frame of reference. To do this, HILARE is equipped with an infrared triangulation system which operates in areas where fixed beacons are installed.

## **2.3 Decision Making and Execution Monitoring**

One important question that arises in the research area of decision-making system organization is the extent of decision distribution in the system, the degree of decomposition of the system in independent modules, and their level of abstraction. The issues of synchronization and communication between modules have to be addressed to answer this question.

The robot decision-making system is composed of several specialized decision modules (SDMs) some of which are implemented on different processors. Several architectures are being examined wherein either distribution or centralization is enhanced. One ap-



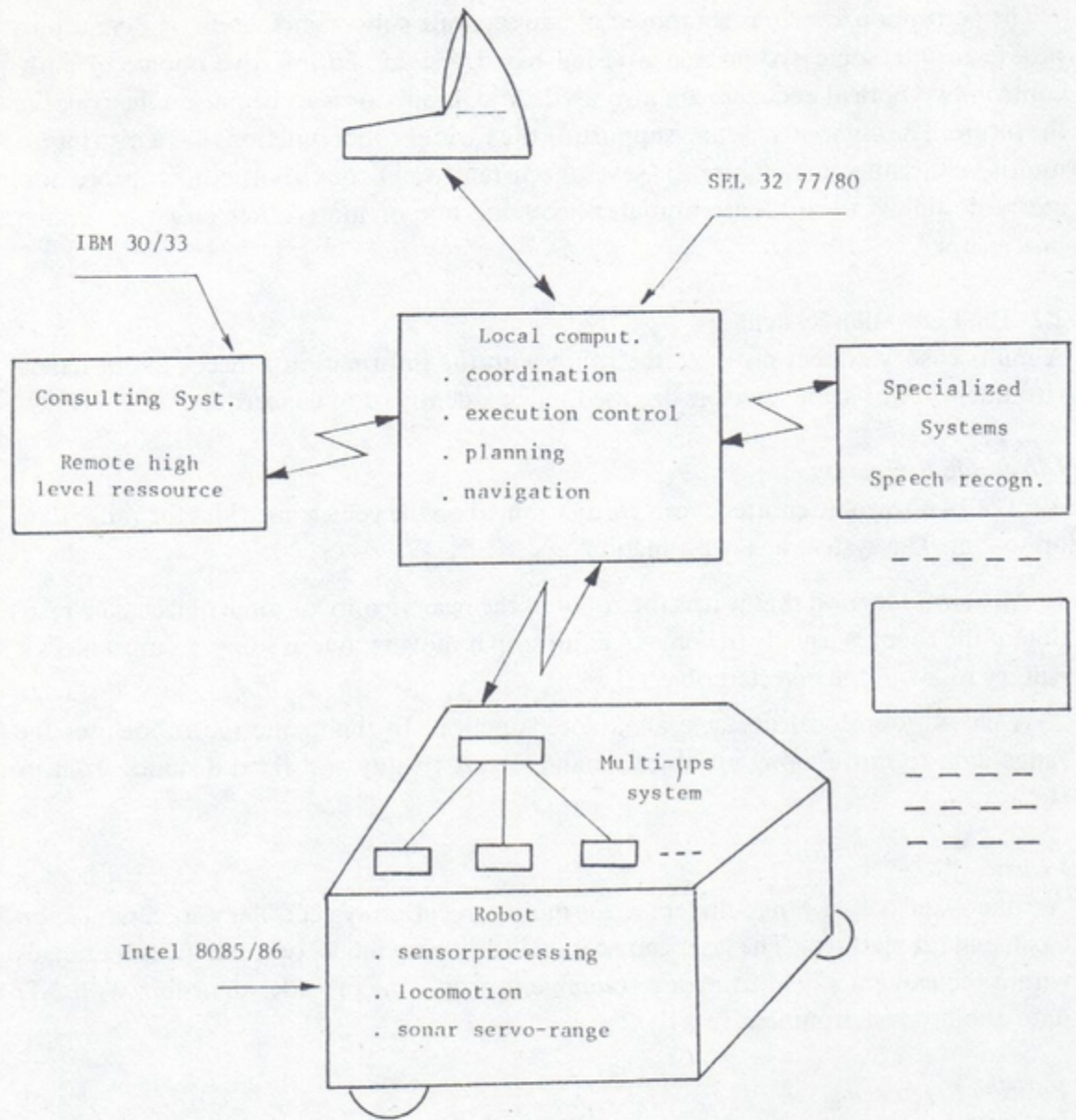


Figure 2



proach is to consider a large number of SDMs organized in a fixed hierarchical structure corresponding to a predetermined ordering. The hierarchy expresses the fact that a lower level module is a primitive of the next one in the structure. On top is a general planner and a plan execution monitor. The execution monitor is a central system through which modules interact. It also controls the robot's interaction with the outer world, i.e., sensing and operator-machine communication.

Another architecture wherein distribution is enhanced is currently being considered. In this structure, the robot decision-making system is composed of a small number of specialized decision modules (GIR 79, CHA 82). Scene analysis, planning, and navigation are three such modules. Each SDM has the necessary expertise in its domain and performs the part of the overall plan that is in its domain. An SDM is composed of a rule-based system and a communication interface. SDMs make use of a hierarchy of specialized processing modules (SPMs) that perform various computations at different levels of abstraction. At the lowest level are the robot's sensors and effectors.

The SDMs that will compose the decision-making system of HILARE include general planner (GPL), navigation and motion control system (NMCS), object modeling and scene comprehension, natural language communication, and manipulator control.

The general planner produces abstract plans that may include parallel nodes. The plan nodes are subgoals to be accomplished by the various SDMs that will generate their own plans to achieve them. Some of the SDMs plans are based on the results of the SPMs and may call for sensing or physical action. The GPL "feeds" the other SDMs with new subgoals depending on the results of the previous steps.

In this approach, the SDMs communicate with each other through a common database. This approach is somewhat similar to HEARSAY II (ERM 80) and to the Hayes-Roths' "opportunistic planning" (HAY 79). The common database is actually partitioned into two components: an announcement database (ADB) and an information database (IDB). ADB and IDB are small and are permanently accessed by the SDMs and are their communication means. The SDMs put in the ADB the subproblems that are not in their domain, and these are considered by the other SDMs as requests or goals to be achieved. The SDMs put in the IDB the results of their plans or any new knowledge they have that is of general interest. Each SDM controls the execution of the part of the plan in its own domain.

### 3 Navigation and Motion Control System

#### 3.1 System Overview

Environment dependent sensory driven navigation is at present the key issue in mobile robots research. And this is still more the case when we consider real-world applications.

The navigation and motion control system (NMCS) is one of HILARE's specialized decision modules. Its domain is all that concerns the robot's mobility activity. The basic procedures it makes use of are routing, navigation, low-level vision, locomotion, position finding, and local obstacle avoidance. The sensors and effector are camera, laser and