I. The Mobile Robot HILARE*

The HILARE project started in September 1977 as an attempt to provide the LAAS robotics group, as well as several other teams interested in this field in Toulouse, with a flexible and powerful experimental support for advanced research work in robotics.

The choice of an autonomous mobile robot was made mainly for two reasons: 1) capacity to provide a variety of problems at different levels of generality and difficulty in a large domain—including perception, learning, decision-making, communication, etc., all of which have to be considered within the scope of the specific constraints of robotics: on-line computing, cost considerations, operating ability and reliability; and 2) the possibility of designing a modular system which could be incrementally built and yet providing interesting and useful research opportunities at every step.

We consider HILARE our most important experimental facility, and we intend to use it to test and demonstrate most of our theoretical work for several years to come. We emphasize that HILARE has no practical purpose in itself; yet we are deeply concerned at every stage of our work with methods, software and instrumentation for advanced applied robotics. This was the only way for us to guarantee a sufficient level of generality for the project.

Physically, HILARE is a triangle-shaped cart with three wheels, the front wheel being a free caster. The cart is built in three levels. The lower level contains the locomotion components (stepping-motors and batteries). The intermediate level contains the electronic systems and the upper level supports the main sensors and, in the future, will be equipped with a manipulator (see Figure 2).

The locomotion of the vehicle makes use of stepping-motors for each drive wheel. They are controlled by a microcomputer which, in our structure constitutes the motion expert. [1]

HILARE is connected to the MITRA 15 minicomputer monitoring its operation via a full-duplex radio transmitter.

At the present time, the perception of HILARE consists of a video camera complemented by a laser range-finder, ultrasonic sensors and a triangulation radar system. [3] The latter system is composed of two infra-red emitter-receivers on a revolving base powered by step motors. The room is equipped with three retro-reflecting "corners" (i.e., beacons). Measurement of angles is made by counting the control impulses. A system of three beacons per "corner" allows parasitic echoes to be eliminated. In addition, one corner was made different from the other two so as to uniquely define the origin.

This system, which is controlled by a microcomputer, allows the robot to determine its location within a few centimeters. Although the triangulation positioning system is only temporarily used on HILARE, such a technique is perfectly valid from an application point of view. One can imagine, for example, placing the reflecting beacons in a warehouse where a mobile robot would be operating.

The vision system, which is still under development, makes use of an image coded with 8 grey levels. The laser range-finder is triggered for a limited number of "shots" to obtain the distance of relevant regions in the image (see Figure 3). The structure of the combined mounting of the camera and the laser is shown in Figure 4.

HILARE is also equipped with ultrasonic sensors arranged as shown in Figure 5. We intend in the near future to increase the number of these sensors, at least at the front of the robot, to improve the capabilities of the

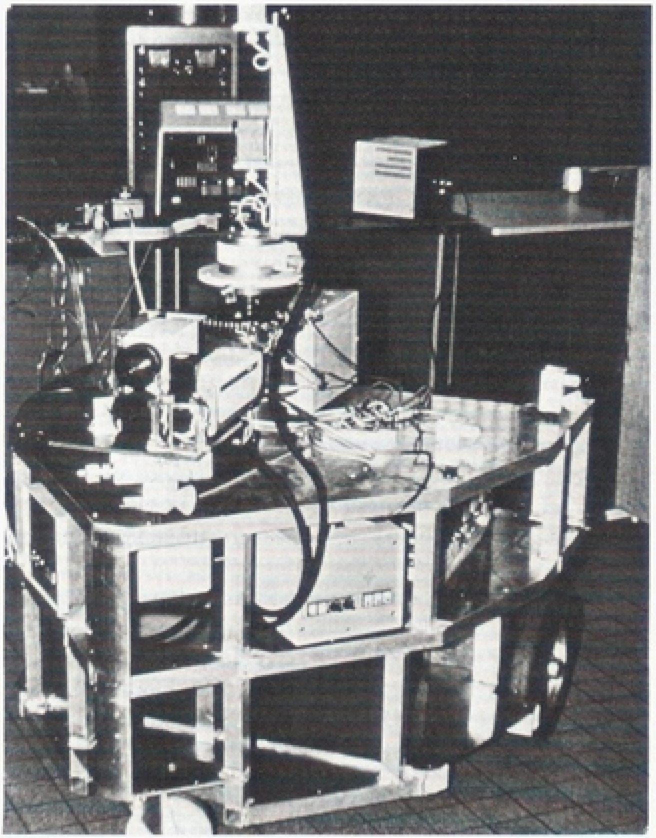

Figure 2. The mobile robot HILARE.

*HILARE: "Heuristiques Intégrées au Logiciel et aux Automatismes dans un Robot Evolutif."

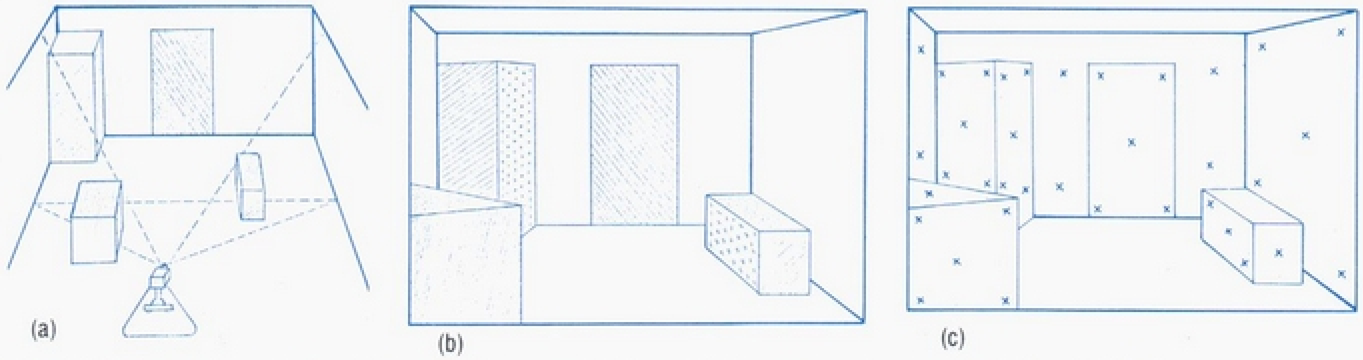

Figure 3. 3-D perception: a) view of the room, b) as seen by the grey-level camera, c) examples of laser "shots."

ultrasonic sensing. The data so obtained will be utilized to provide: 1) a proximity alarm; 2) a general use range-finder; 3) navigation in special cases (along a wall, or to by-pass an obstacle, for example) without using the vision.

A schematic view of HILARE, showing all the afore-mentioned sensors, is given in Figure 6.

We now consider the distributed decision making of HILARE, which follows the general scheme given above. [7] The design can be viewed as decisions through multiple cooperating expert modules together with a high-level coordinator in a hierarchical structure.

The expert modules have their expertise in a variety of overlapping domains (e.g., object identification, navigation, exploration, itinerary planning). The modules consist of 1) specialized and redundant knowledge bases, 2) algorithms and heuristics, 3) local error-processing capabilities, and 4) communication procedures. Modules may have access to one another as primitive action units. The coordinator activates modules based on an analysis of the current situation.

We are designing and programming a relational-level planner at an advisor level. A plan at this level is a flexible dynamic structure which coordinates the achievement of desired goals.

Due to the incremental and open-ended nature of HILARE's design we consider *Production Systems* (PSs) as a viable research tool for relational-level problem-solving. Thus, we are writing the planner terms of a PS architecture in the spirit of M. Rychemer. [11]

The expert module for navigation [7] considers the basic problem of moving a robot from an initial location (R) to the target (G) within a given place. This involves obstacle avoidance, pathfinding, and search trajectory minimization.

Currently, obstacles are defined as polyhedral objects, whose floor projections fully determine the navigation problem, and they can be located either by initial information of by robot perception (see Figure 7). Each obstacle projection is represented as an ordered list of segments in a counter-clockwise sequence.

Empty areas are defined as convex polygonal cells which may include obstacle segments. A trajectory within such cells can be considered as a straight line between entry and exit segments. Two adjacent cells have connectivity through common segments which are traversable by the robot. Thus, a connectivity graph provides the structure necessary for pathfinding.

This graph is fairly similar to the connectivity graph describing the topology of a group of rooms, which will be used by the expert module for intinerary planning. We expect in both cases to be able to implement some sort of learning process, which is useful when the robot is discovering an unknown environment by itself.

To conclude this presentation of HILARE, it is noted that the ongoing work on this robot includes:

- sensory integration,
- implementation of a multi-microprocessor structure,
- developing various expert modules,
- vision algorithms with grey levels,
- design of the high-level planner using pattern-

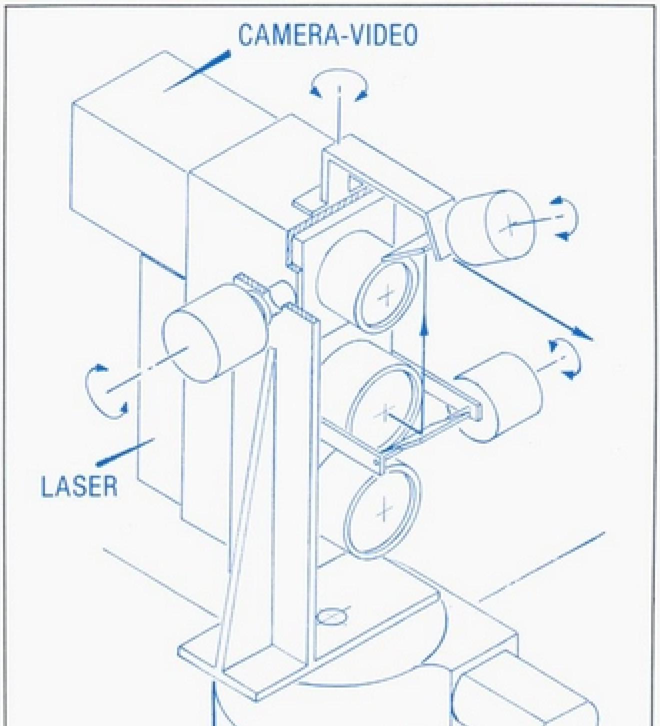

Figure 4. Laser range-finder and camera mounting.

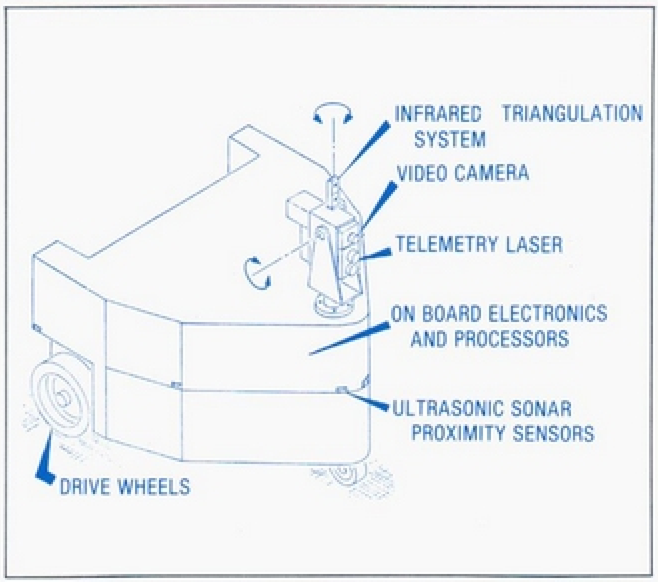

Figure 6. Schematic view of HILARE's current hardware arrangement.

directed inference systems (PDIS) techniques.
- implementation of a control by voice, with the collaboration of two other laboratories (L.I.M.S.I.-Paris for the voice decoding and L.S.I.-Toulouse for sentence understanding).

II. Blocks-World Assembly Experiment Using Task-Specific Planning.

Flexible Automated Assembly Systems are among the most challenging problems that many groups working in Robotics currently encounter. Several studies designed to contribute to this field of research are being carried out at LAAS. This section will describe one study which is especially concerned with two important aspects of robot assembly problems: System Integration and Plan Generation. [10]

Blocks-world models have often been noted as relevant and interesting research vehicles by different authors. [12-13] In our experiment the assembly robot system operates in a discrete parallelepiped world containing any finite number of identically sized blocks (7x7x3.5cm). Cubes (as they are called) belong to one of five possible classes; the class of a cube is represented by a pattern on its upper face (i.e., circle, rectangle, triangle, five-pointed star, or eight-pointed star).

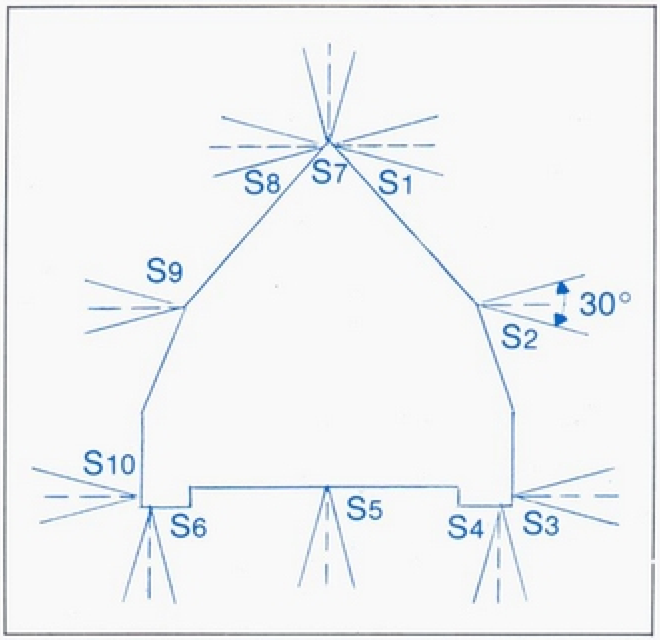

Figure 5. Arrangement of HILARE's ultrasonic sensors.

System Architecture

The blocks-world assembly experiment makes use of a robot called the "X-Y-Z Table" or "transfer robot." Its physical structure (see Figure 8) is that of a rectangular work area above which a manipulator operates. The manipulator has four degrees of freedom X-Y-Z-θ. The first three are translations along orthogonal axes and the last one a rotation around the vertical axis. Various devices can be mounted on the manipulator, ranging from simple magnetic or vacuum grips to sophisticated wrists. In the past, a sensor making use of the LAAS artificial skin was also mounted to perform parts recognition by touch sensing. [2] However, the sensor commonly used is a video camera whose axis is parallel to the vertical axis and which may be moved along the two other orthogonal axes.

The X-Y-Z table is microprocessor-controlled, and the video camera system consists of a Sanyo VCM 2000 video camera (8 MHz bandwidth) coupled to an Aerazur INF 625 image digitizer. The digitizer transfers 6-k bytes by Direct Memory Access to the computer (a MITRA 15) executing the vision software (24,576 points per image at 2 bits per point).

The computing structure consists of 3 levels of processors: 1) an IBM 370/168 remote time-sharing system, 2) a Sems 16-bit MITRA 15 minicomputer (64-k bytes) and 3) an Intel 8080-A microcomputer. The MITRA 15 computer is the system coordinator (see Figure 9); it controls executive functions and the communication between the user, the IBM 370, and the assembly robot. There is a control terminal for the system user and a line-printer for recording diagnostic and execution traces. The software system, written in FORTRAN and assembler, requires 72-k bytes and executes in overlayable segments. It also includes the path-finding and vision software. The remote IBM 370 runs under TSO and, therefore, it considers the MITRA 15 as an ordinary terminal. They are connected by a 300 baud half-duplex line. The IBM 370 executes an of the approach phase is about 0.3 millimeter. To achieve the part-mating operation properly, we have designed a compliant wrist. The wrist is rigid along the insertion direction and compliant along the others in a passive way (see Figure 13).

The experiment has been carried out very successfully. The current work is concerned only on minor improvements to reduce the operation cycle time.

IV. Conclusion

In this paper, I have described three experiments conducted at LAAS in the field of Robotics Research. Although they do not cover the whole work that we are currently pursuing, they give a good illustration of the way we are doing our research in robotics: we try to maintain a balance between long-term basic research and medium-term research oriented toward industrial applications.

We all find the field of robotics a very exciting one, and we have the feeling that we are participating in something really important for the future of our society.

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Glossary

heuristic: *a technique used in a problem-solving system that may improve the program's performance. The term often refers to the methods used to organize the search for the solution to the problem.*

production system or pattern-directed inference system: *a method of programming in which a collection of "if-then" rules define the system's behavior. Whenever the "if" part of any rule is satisfied by facts in the database, its consequence is automatically performed.*

world-model: *a database used by a problem-solving system in which the facts represent the program's beliefs about the state of its environment.*

Robotics Age wishes to acknowlege the kind assistance of Dr. Georges Giralt, director of the LAAS robotics program, without whose help this report would not have been possible.