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An outdoor robots system for autonomous mobile all-purpose platform

Takao Okui *, Yoshiaki Shinoda

Fourth Research Center, Technical Research and Development Institute, Japan Defence Agency, 2-9-54 Fuchinobe, Sagamihara, Kanagawa, 229 Japan

Abstract

Autonomous ground robots for exploring natural environments are developed in our research center along with the recognition of the configuration and the obstacles.

The three key technologies for such a robot are the study of the locomotion mechanism, the autonomous system and the multiple robot control.

This paper will discuss the definition of rough terrain and the establishment of the fundamental precondition based on the results of the experiments we conducted. It will also propose an autonomous system for robots taking not only its configurations into consideration, but weather, lighting and temperature conditions as well.

Keywords: Behavior-based intelligence hierarchy system; Obstacle detection; Tactile sensor

1. Introduction

The goal of our work is the development of an autonomous system that does not depend on the controlled condition of industrial settings, but functions in an unstructured outdoor environment. The difficulties to realize the autonomous system are not only that robots have the limitation of the capacity of the hardware itself (e.g., uncertainty and error), but also that the architecture and the data structure for robots remains unsolved.

Recently many architectures for autonomous intelligent robots are being proposed and demonstrated. The Carnegie Mellon Navlab is navigated on roads [10]. The Carnegie Mellon Ambler was developed in response to autonomous exploration of planetary and lunar surfaces [2,3,9]. The MIT Mobile Robot group demonstrated complex control systems, otherwise known as subsumption architecture, for augmented finite state machines [4,5]. However, autonomous robots have yet to be completed. Our approach to the autonomous system was to first consider the definition of rough terrain. Rough terrain (Fig. 1) consists of a variety of artificial and natural objects, such as trees and ditches, and also changes in configuration, weather, light and so on. We have analyzed and defined the terrain outdoors as shown in Fig. 2. It is obvious that many kinds of robots locomote on such a rough terrain autonomously. Therefore, we have established the following preconditions:

(1) The robot is as small and light as possible and has high mobility against rough terrain. Therefore, we introduced the concept of giving the robot the ability to change posture.

(2) The robot has a map which describes the rough terrain between the start point and the goal point. However, the map is rough and does not have complete information on obstacles,

* Corresponding author.

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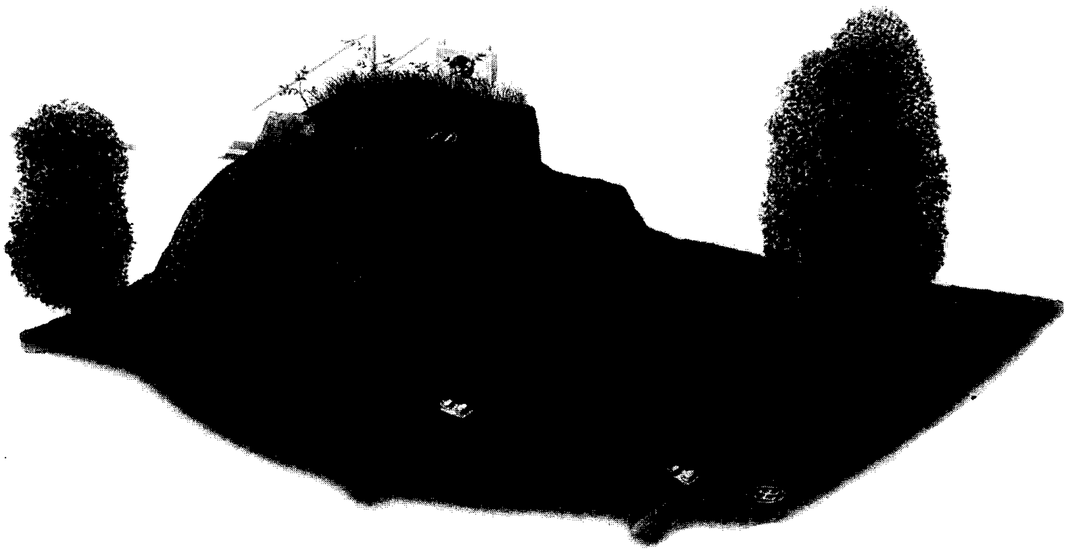

Fig. 1. Rough terrain.

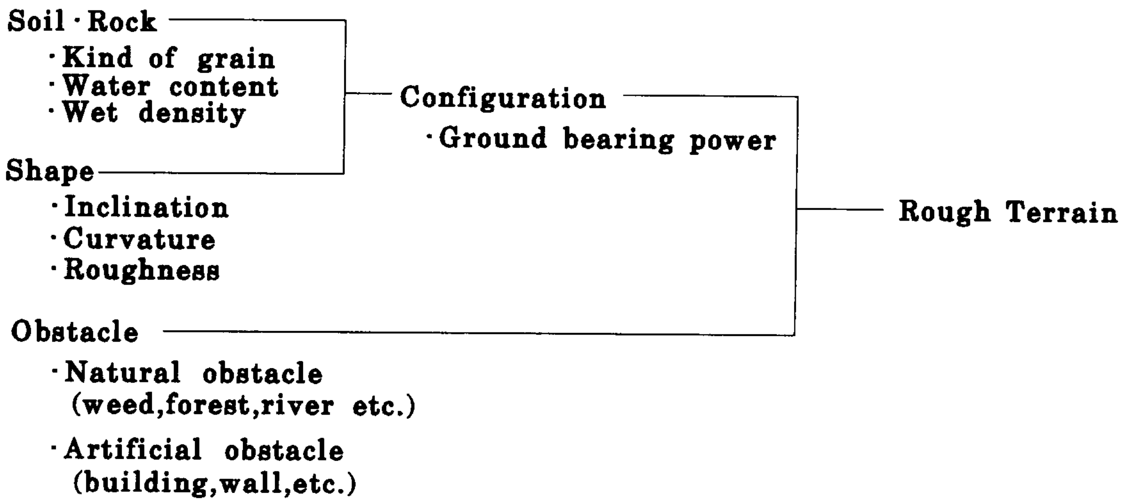

Fig. 2. The definition of rough terrain.

wash-boards, changes in configurations, and so on.

(3) The robot has a database of its postures which partially describes how to traverse rough terrain.
(4) A man indicates to the robot the start and goal points in which the robot will automatically create a global path and will locomote along that path.

By using a model (Fig. 3), we started the autonomous system, which does not depend on a locomotive mechanism, under the above preconditions. We have named this robot the Autonomous Mobile All-purpose Platform (AMAP).

In this paper, we are proposing an architecture for an autonomous system for AMAP predicated on the behavior-based concept. This concept is becoming widely adopted. We have extended this and are constructing the behavior-based intelligence hierarchy system.

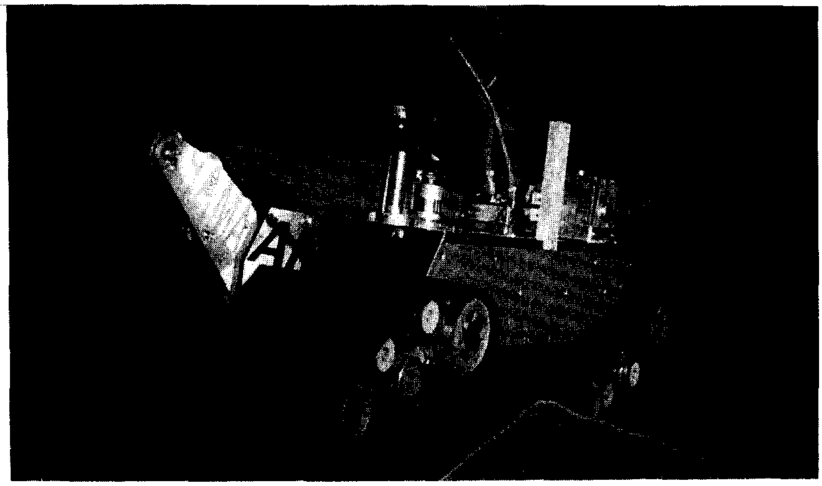

Fig. 3. AMAP.

The remainder of this paper is organized as follows: In Section 2 the system concept is described. The behavior of robots that locomote on rough terrain is discussed. In Section 3 system structure is presented. This structure was constructed by decomposing the architecture into task-achieving modules along the flow of the function. Conclusions follow in Section 4.

2. System concept

A robot must execute a diverse array of behaviors in order to move on an outdoor rough terrain (Fig. 4). Through our experience of operating AMAP on a rough terrain model and analyzing the resulting behaviors, we developed a concept for the architecture. As a result, we have classified the behaviors into six tasks to create the autonomous system as follows.

(1) *Global path planning:* plans the global path by using a map and makes improvements upon this map.
(2) *Task management:* selects from the following four tasks and sensor control for obtaining the information the robot requests.
(3) *Locomotion on unknown rugged configurations:* recognizes a rough terrain in front of the robot and makes motion planning for traversing rugged configurations which are not described on the robot's database. Rugged configurations are defined as the topography that the robot in the basic posture cannot traverse but by changing posture can.
(4) *Locomotion on known rugged configurations:* recognizes configurations in front of the robot and makes motion inferences by selecting from the database, which describes these rugged configurations and the way to traverse them.
(5) *Obstacle avoidance:* detects and avoids rough terrain that the robot cannot locomote and traverse.
(6) *Locomotion on plain fields:* moves along the global path, conducts real time control, and detects changes from plain fields to rugged configurations or obstacles.

Through analyzing these tasks (Fig. 5), we have created a behavior-based intelligence hierarchy system that deals with a diverse group or requested behaviors [8].

3. System structure

Before building the system flow on the basis of the previous system concept, we introduced five function stages. The stages are sensing, processing, recognition, judgement and control. The sensing stage consists of sensors' hardware for obtaining the data about the environment around the robot. The processing stage is the extraction of signals from the sensors. The recognition stage is the generation of information for judgement. The judgement stage consists of motion planning to indicate where to go and what to do. The control stage constitutes

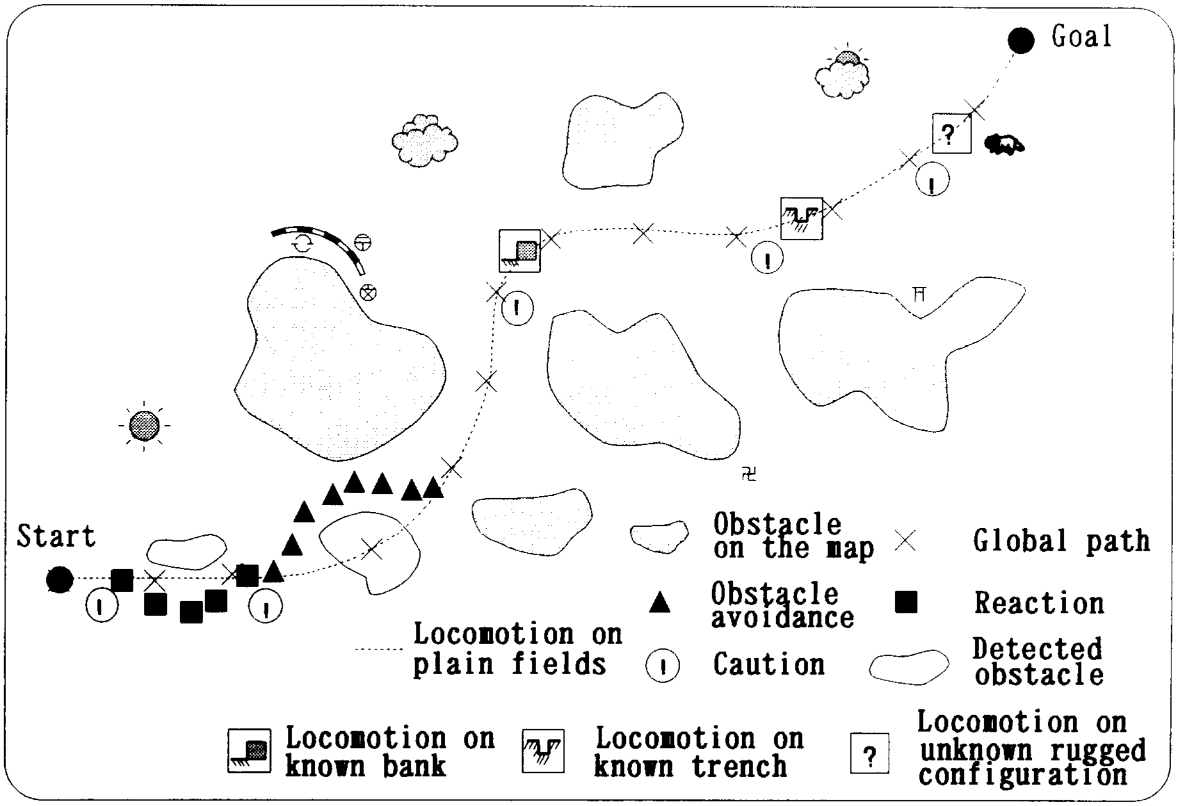

Fig. 4. The outdoor autonomous locomotion.

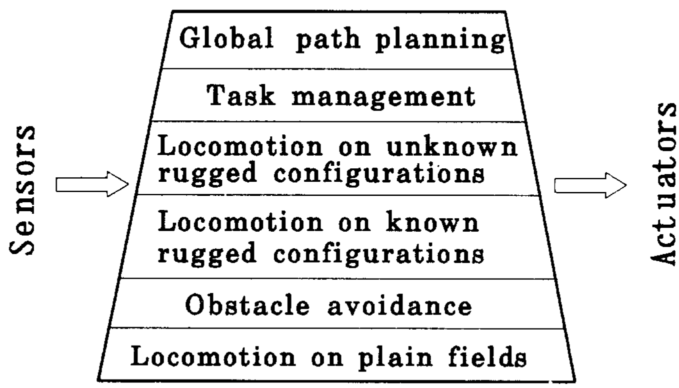

Fig. 5. Behavior-based intelligence hierarchy system.

motion control depending on the mechanism of the robot.

In each task and stage we have developed modules by considering the flow of data and distributivity. Therefore creating a system flow (Fig. 6). Each module is as follows:

(1) *Location:* makes an estimation of the robot's current location and makes any corrections to localize the robot's position.
(2) *Contact force:* detects the amount of contact force for soft terrain.
(3) *Range image:* acquires range images. This

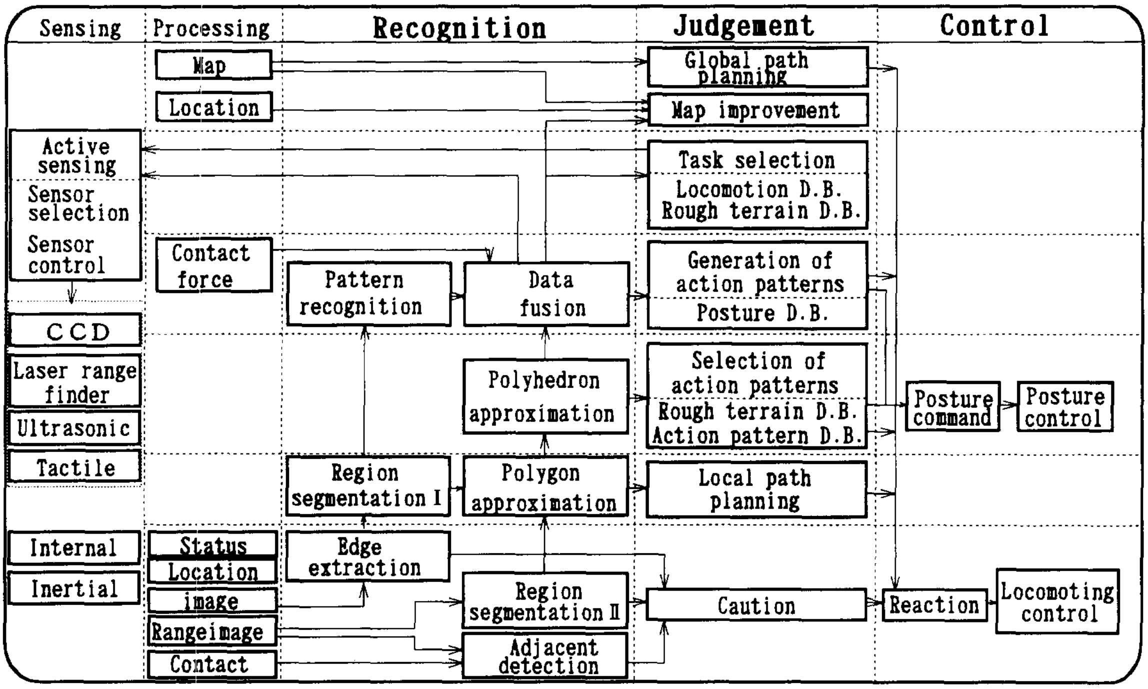

Fig. 6. The flow of autonomous system.

module is a kind of pixel-level fusion that can be used to increase the information content associated with each pixel in an image formed through a combination of multiple images. We are obtaining these images by using a time-of-flight-type laser range finder (Fig. 7) and CCD cameras.

(4) *Contact:* touches configurations and obstacles the extraction of contours. We made a rubber actuator tactile sensor with elasticity to react to sudden changes in configuration (Fig. 8).

(5) *Edge extraction:* extracts the boundary between plain fields and otherwise, and sends the information to Caution [8]

(6) *Region segmentation* I*:* segments image data from CCD cameras by analyzing the texture of the photo to detect the areas where the robot cannot locomote.

(7) *Pattern recognition:* detects and recognizes moving objects.

(8) *Region segmentation* II*:* segments range data into plain fields, convexs, concaves and blind spots. We have defined segmentation by height (Fig. 9) [6,7].

(9) *Polygon approximation:* approximates the boundaries of regions that are obtained by Region segmentation I and II to a convex hull

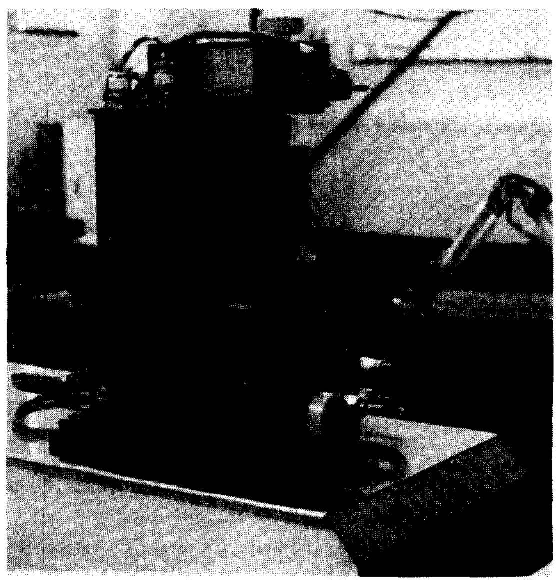

Fig. 7. Laser range finder.

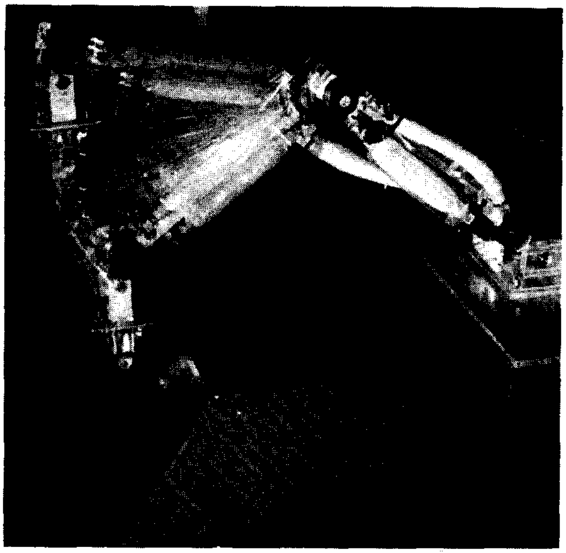

Fig. 8. Tactile sensor.

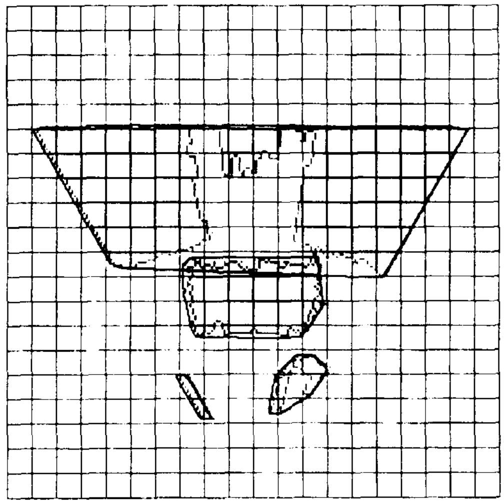

Fig. 10. Polygon approximation.

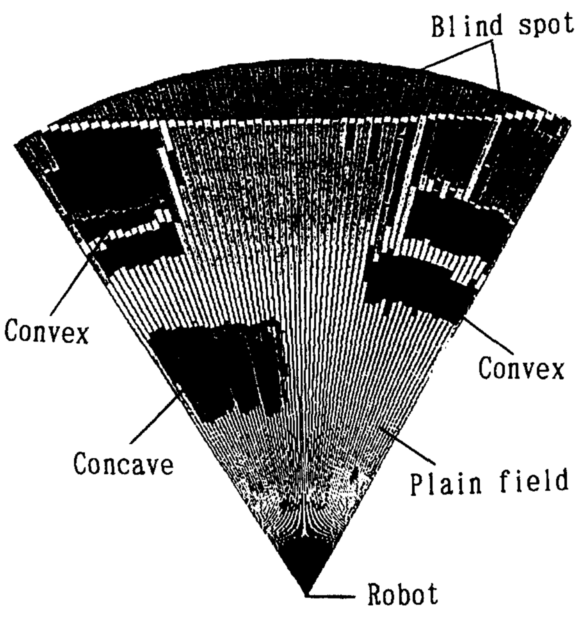

Fig 9. Region segmentation.

(Fig. 10) and labels each region as "possible to move" or "impossible to move".

(10) *Polyhedron approximation:* approximates the shape of configurations and obstacles by using inclinations in relationship to a polyhedron [7].

(11) *Data fusion:* recognizes three dimensional shapes, moving objects and softness [1]. This module is a kind of feature-level fusion that can be used to both increase the likelihood that a feature, extracted from the information provided by the sensors, is recognized, and to create additional composite features for use by the system. It also is a symbol-level fusion that allows the information from the multiple sensors to be effectively used together at the highest level of abstraction.

(12) *Adjacent detection:* detects changes around the robot by using tactile sensors and supersonic sensors, and produces obstacle fuzzy vectors that express the distance and direction of obstacles.

(13) *Caution:* detects actual changes in plain fields to make a robot stop and produce caution fuzzy vector (Fig. 11) from obstacle fuzzy vectors. This module is a kind of signal-level fusion which refers to a combination of signals from a group of sensors. Their objective is to provide a signal that is usually of the same form as the original signals, but it is of greater quality.

(14) *Local path planning:* plans a subgoal, which describes the position and the direction the robot should locomote, in the sensing area of the robot and guides the robot to avoid obstacles with Reaction module.

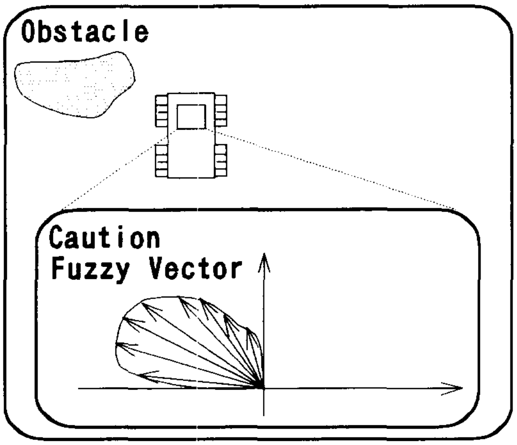

Fig. 11. Caution fuzzy vectors.

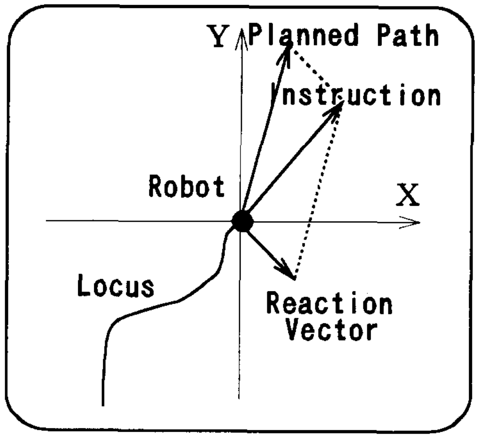

Fig. 13. Reaction.

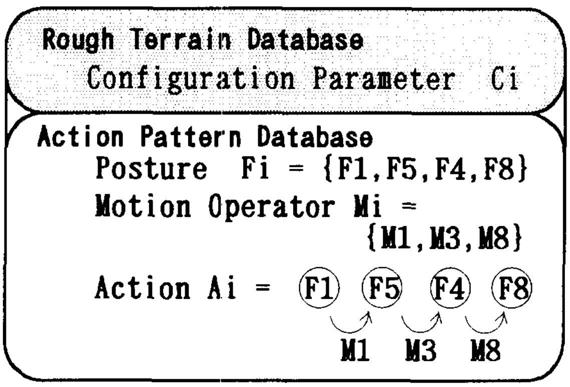

Fig. 12. Database of actions.

(15) *Selection of action patterns:* selects from the database of actions (Fig. 12) to traverse rugged configurations.
(16) *Generation of action patterns:* generates sequences of posture by using the posture database.
(17) *Task selection:* makes a judgement of the task based on the ability of locomotion and the result of recognition.
(18) *Map improvement:* matches the global and local maps and makes improvements based on the obtained environmental information.
(19) *Global path planning:* generates a global path on the map.
(20) *Reaction:* reacts to avoid rugged configurations and obstacles in a manner similar to a human's unconditioned response by synthesizing the planned path and the reaction vector (Fig. 13).
(21) *Locomoting control:* stabilizes the body of the robot in order to deal with small changes in configuration. Locomotes by obeying speed and direction commands.
(22) *Posture control:* changes control of posture by obeying the posture command.
(23) *Sensor selection:* selects sensor to obtain information the robot needs.
(24) *Sensor control:* controls the direction, the visual field and the magnification of the sensor to obtain the necessary information.

We have constructed the experimental system in our laboratory in order to study the system flow (Fig. 14). All of the devices, which belong to Sun's engineer work station, are connected by Ethernet to conduct parallel distributed processing and to increase the efficiency of programming. The signals from the sensors are taken in through the VME-bus and are processed by devices installed with real time UNIX. On the contrary, the signals to the robot are processed by device installed with real time UNIX and are taken out.

4. Conclusion

In this paper, we defined rough terrain, discussed the autonomous system for robots which locomote on rough terrain, and proposed the behavior-based intelligence hierarchy system which shows that diverse sets

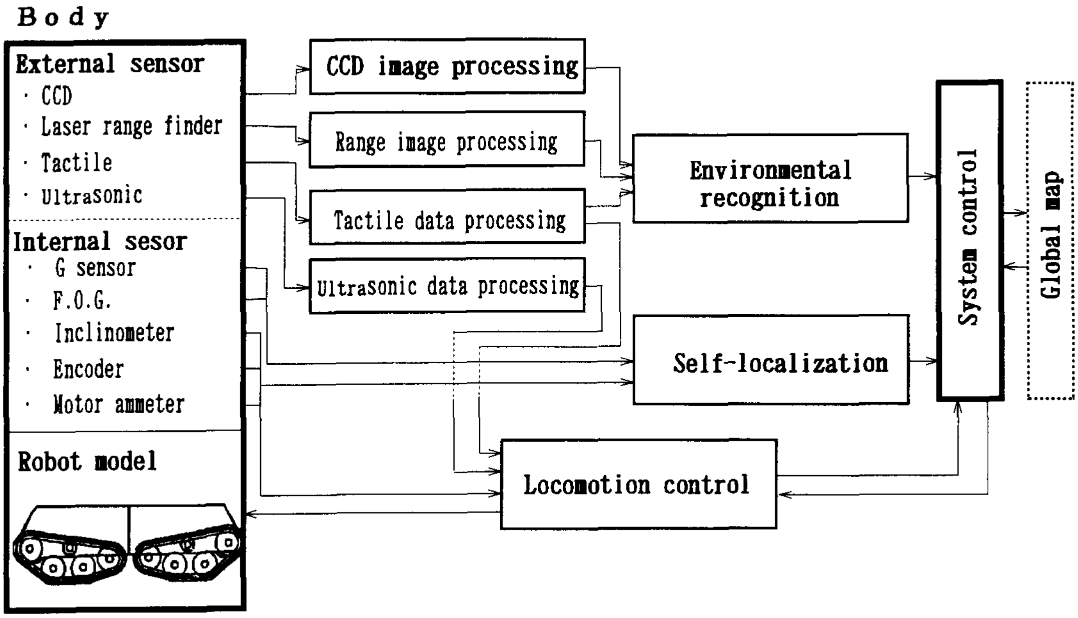

Fig. 14. The experimental system.

are feasible. We created the Autonomous Mobile All-purpose Platform (AMAP) with the ability to change its posture and equipped AMAP with external sensors such as the CCD and the laser range finder and internal sensor. We experimented on several modules which include Location, Range image, Contact, Edge extraction, Region segmentation II and Polyhedron approximation. We obtained some interesting results. We have three objectives for the future. First, we plan to create a process flow for each module by doing more experiments with AMAP. Second, we will study the properties and limitations of the architecture. Finally, we will clarify the true architecture and data structure for autonomous robots.

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