A Distributed Architecture for Active Perception in Autonomous Robots

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ABSTRACT

Present work describes the developed architecture for sensor information integration in a mobile robot. Hardware and software modules work locally with sensors signals, distributing the fitness functions over a parallel processing scheme. This organization tries to overcome real time constraints when dealing a with dynamic system-environments. A distributed network of DS5000 Dallas microprocessors and T800 transputers assisted by several DSP's, is addressed for first stages of sensors signals accommodation and generation of low level survival behaviors.

Human knowledge in transferred to the perception modules as Fuzzy Logic inferences located on each processor. A set of decision rules account for efficient decisions making using a small number of linguistic terms that condense rough sensor data by means of membership functions representation. System experience can be modulated with existing algorithms according with some pre-defined safety conditions.

1. INTRODUCTION

Ultrasonic pulse-echo modules provide obstacle information to many commercial mobile platforms (Robosoft, Nomadic, TRC, RWI, Odetics) and mobile robot prototypes (Robart II, TOTO, BOSS). Usually, a peripheral distribution of transducers gives radial free path in the robot neighborhoods. Ultrasonic sensors are active devices capable to improve the measurement and to deliver significant information relative to either multiple obstacles, echo morphology, obstacle shapes and movement, data correlation between close transducers, etc. [1].

Infrared detectors have been often employed as passive human presence detectors (hot surface) or active object detection by illuminating with an I.R. source [2], [3]. Both are very noisy magnitudes from the classical calibration point of view, but they can offer relevant information closely related to other variables such as sound or temperature.

Increasing complexity on the sensing information flow and on the computing algorithms implies for the system, both higher capability of internal communication channels and processing power. If complex information requires special hardware and software strategies, the uncertainty inherent to real environments needs appropriate software representations [4]. Dynamic environments, noisy signals, control errors, non linear or time variant sensors, hardware failures, unexpected events, evolving capabilities, are usual sources of uncertainty for decision making system resident in an autonomous robot [5], [6].

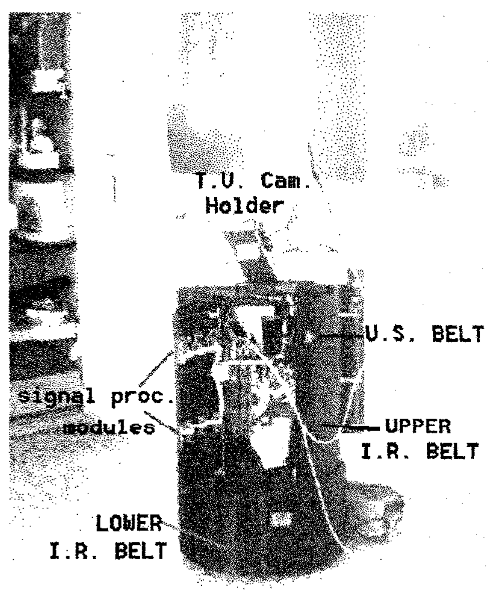


Fig.1 Pheripheral sensors on a B21 robot

This low level architecture is being demonstrated on two mobile robots: a commercial platform B21 (Fig.1) and a prototype BOSS (Fig.7) both endowed with multiple sensor systems.

2. HARDWARE LAYOUT

As a first approach, a multisensor belt has been designed and built for the mobile platform BOSS. Ultrasonic pulse-echo transducers search for obstacles in the surrounding environment, Fig.2. Light and color distribution around the platform could not substitute an image processing system but can cooperate to locate an open door or window, to detect the distance to the wall or the presence of an obstacle. External sources of sound are also a very important issue in the perceptual human domain, not only for communication purposes but also for motion and presence detection by locating the sound sources. Passive infrared detectors are able to recognize warm surface such as a human body or a sunny window.

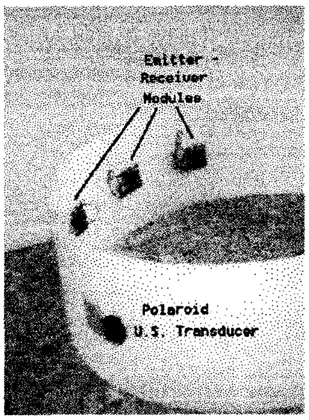


Fig.2 Sensing modules

All these directional sensors have been fitted to cover a 30° angle, from the robot heading with some overlapping between adjacent positions, Fig.3. This conforms local teams of heterogeneous sensors

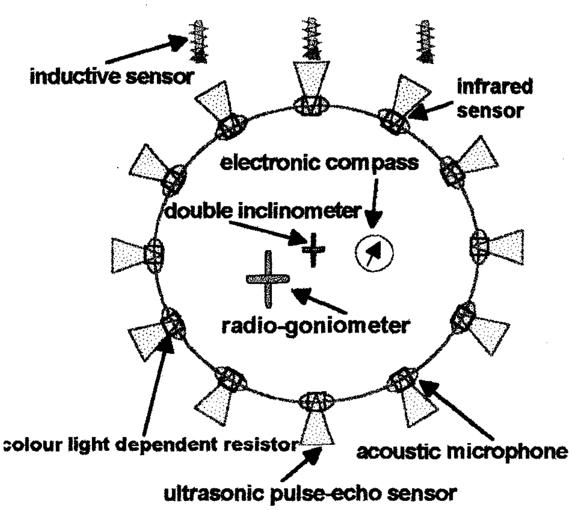


Fig .3 Local sensor teams

dedicated to acquire complementary information coming from each angular sector of the robot contour. Thus, a local sensor team integrates U.S. data, sound, I.R. and visible light and color for each angular sector or location in the peripheral sensing belt.

A hardware low level architecture, built by multiple micro-controller processors, offers easy input- output interface, modularity and expandability. Flexible pre-processing circuits for each signal are directly managed by this micro-controllers layer setting the adequate gain, filters, A/D resolution, and sampling rate. RAM re-programmable chips (with battery backup memory) increase the system flexibility by dynamically changing the processing algorithms. Upper levels of the processing hierarchy are built by high power parallel processors from Inmos with easy link to the human designer and operator, Fig.4.

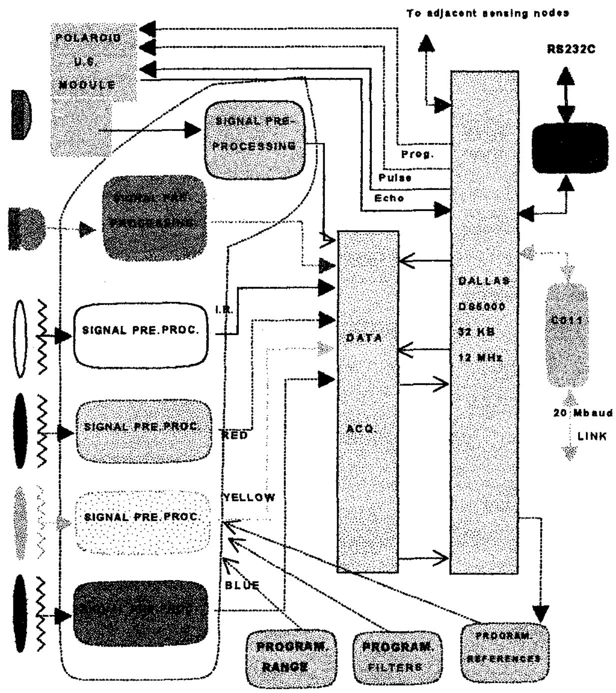


Fig.4 Local processing node

Each micro-controller node manages only its own sensor team and preprocessing circuits for signal conditioning but receives information also from adjacent sensor modules (Fig.5). This type of redundant information permits an immediate answer to time-space incremental response (as lateral inhibition in visual path processing).

Programmable references, amplifiers and filters at the analog stage provide computer controlled procedures to select relevant data from the first stages in the information processing flow. High efficiency physiological mechanisms in perceptual processes like

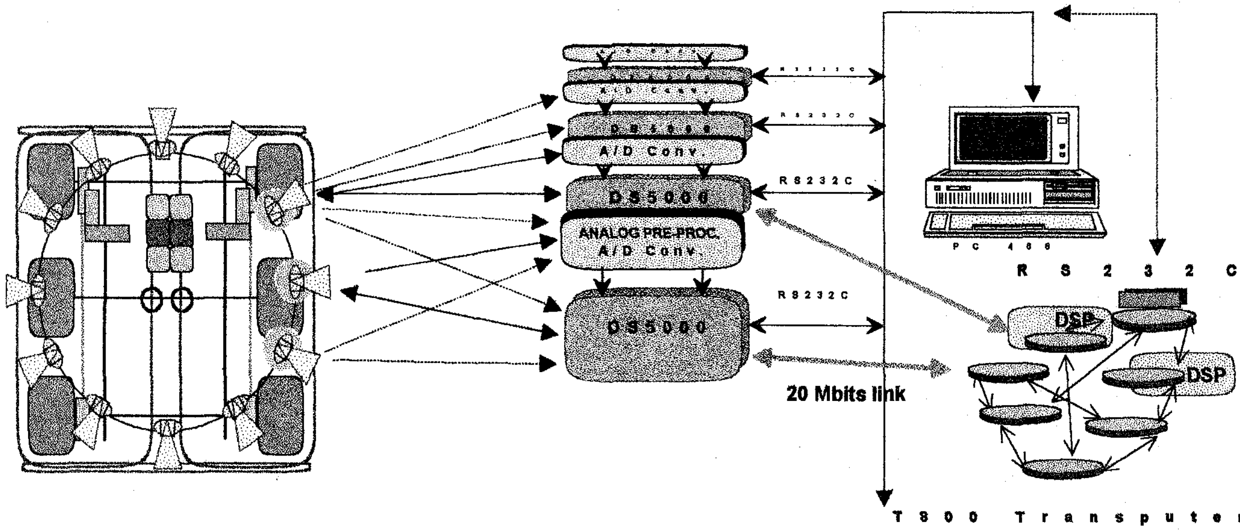


Fig.5 Local Distribution of Processing Tasks

habituation or accommodation in time and border detection in space can be easily implemented as low level processes in the proposed architecture. Redundant topology also prevents for fault detection, evaluation and repair at physical sensors or preprocessing levels.

Active perception constitutes the basis of our second approach due to the following reasons:

1. The number of sensors and processing nodes can be drastically reduced maintaining similar functionality in a quite simple architecture
2. For a mobile robot the relevance of lateral, frontal and back sensors is clearly different. Attention mechanisms perform a distribution of the available resources in time and space, increasing the data flow from relevant sources such as obstacles, motion direction, high speed, approaching objects, etc.

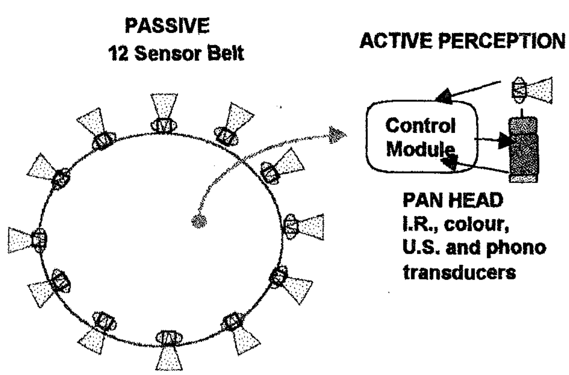


Fig. 6 Static vs. dynamic perception

A multisensor active module has been developed by controlling the direction of the transducers team with a servo motor device (Fig.6). The μcontroller has identical processing capabilities that the former belt node but holds out for the control of the sensors direction by programming the single d.o.f. servo control loop. Peripheral space distribution of sensing information is multiplexed in time through time series representing consecutive positions of each transducer when supported by the rotating head.

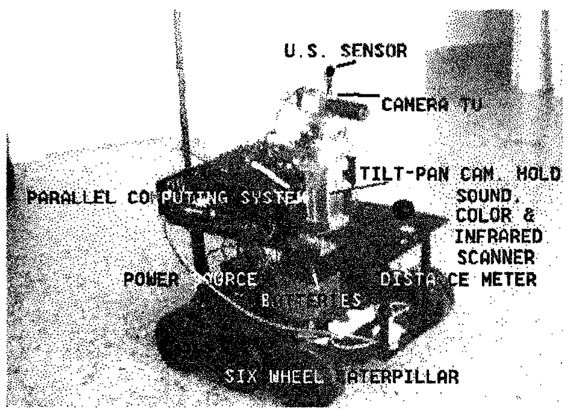


Fig.7 Caterpillar type autonomous robot

A caterpillar six wheels mobile platform (Fig.7) endowed with this active multisensor module has been used to demonstrate its efficiency in local robot navigation. Real time image processing requires a parallel high throughput processing hardware following the same methodology [7] which must be coordinated for global decision making.

3. PROGRAMMING MODULES

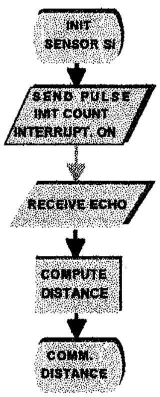


Fig 8 Single event processing flow

Signal processing and control algorithms are necessarily integrated in active perception architectures. Both, sensor time response, i.e. flying delay for pulse-echo U.S. distance measurement, and motor rotating speed determine the highest sampling rate. Position accuracy and sensor beamwidth establish the maximum angular resolution.

Reactive behaviors generate control commands as a response to environment stimuli. On the contrary, elementary ultrasonic. pulse-echo distance measurement is an exploratory mechanism (Fig.8) in which initiative to measure must be taken by the system by sending to the pulser the appropriate command. Several questions arise at this lowest level of the decision making architecture, considering just a single type of transducer and only one orientation:

1. When / where the rotating head must initialize a measurement cycle?.
2. What is the required resolution in time (sampling rate) and distance (error)?.
3. How deep memory is required at this level to store information of a significant time window in order to perform signal analysis?.

Active perception for the whole peripheral environment requires more decision making mechanisms to establish the orientation and a timing strategy to optimize sensing resources (Fig.9). Simple algorithms, such as constant regular intervals, are robust and easy to program but misuse system capabilities as: attention- habituation trade-off, non-homogeneous representation like foveatization, short-long time memory.

On the other hand a large and sophisticated decision making process is difficult either to design or to program. It may lack robustness and deliver results hard to interpret. Difficulties specially turn out when data from different mobile sensors must be jointly considered for global decision making.

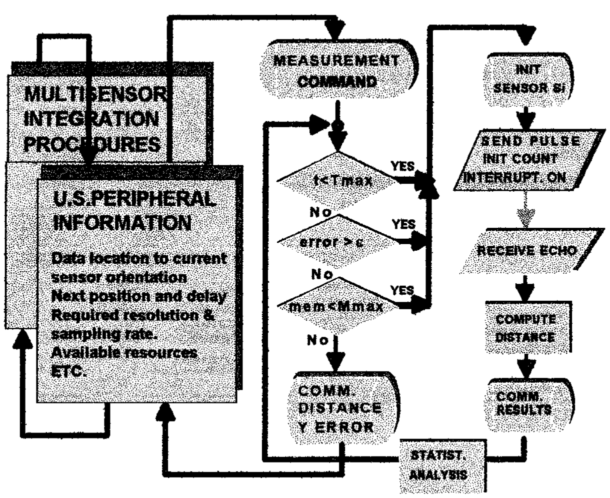


Fig. 9 Multiple sensors, locations and events

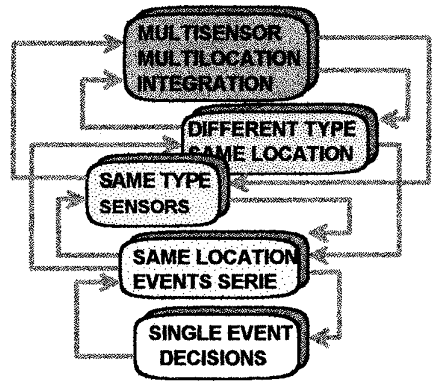


Fig. 10 Functional architecture

The aim of the proposed architecture (Fig.10) to deal with the complexity and the uncertainty inherent to multi-sensor systems has been gathered in a hierarchical and distributed level architecture able to account for active perception within a fuzzy logic heuristic knowledge representation [8].

Driven by an efficiency criterion the system condenses the huge and noisy information flow from the environment in a few labels (Fuzzy Sets) that are sent to the upper decision making levels Conventional calibration functions have been reduced to small set of

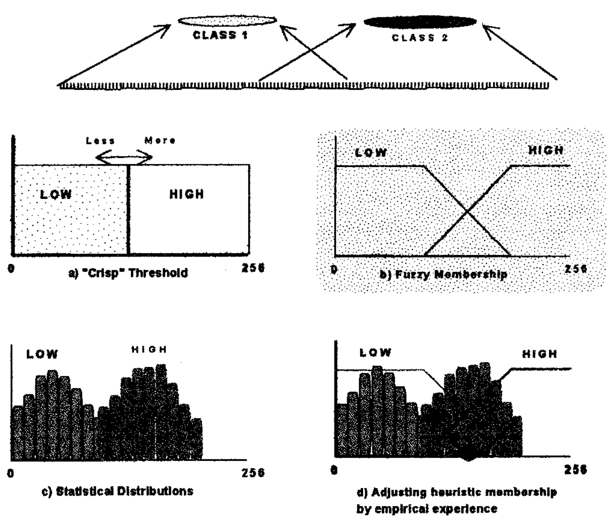


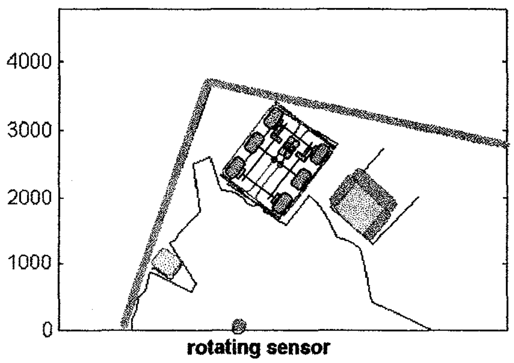
Fig.11 Mapping strategies

symbols with simple and consistent syntax rules. Functional modules, schemes or agents perform consistent decision making, to interpret real world information according to the human knowledge which has been transferred to the system as a program source code and command parameters.

Fuzzy Logic Membership functions (Fig.11) easily allow a flexible ascription of numerical intervals to the selected symbols. Threshold values or whatever "crisp" assignment, is considered as a particular option with non- overlapping, trapezoidal shape membership function. Empirical learning has a comfortable room in this approach by tuning the heuristically defined membership functions by means of examples-based learning techniques [9].

5. SOME RESULTS

An environment with a paper basket, the caterpillar robot and a chair in a corner of the laboratory (Fig.12) can be perceived by the ultrasonic rotating sensor with different degrees of resolution.

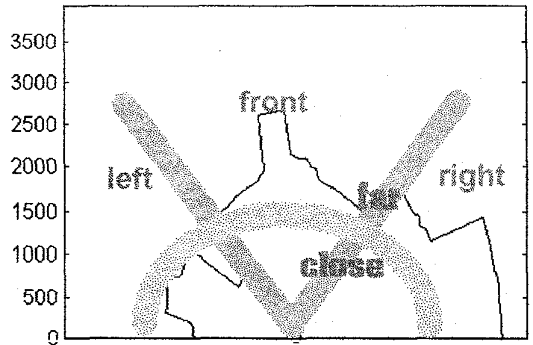


180° range / angular resolution =4°

Fig.12 Ultrasonic perceptual environment

Efficient decision making deals with simple representation frames which can be either empirically or heuristically defined. Maximum resolution models do not improve images, due to the increase in noise, system complexity and time consume. For most navigation purposes the complex and noisy map obtained with 2° of angular resolution (90 angular orientations), and 0.4% distance resolution (that is 8 bits), can be represented by means of 3*3 symbols in a fuzzy vocabulary: " There is nothing at right close to the robot", "almost nothing in front of it", and "there is a high possibility to find an obstacle close to the left" (Fig.13).

Thus, the system can detect echoes far in the side of all three orientations. Automatically upper adjacent level

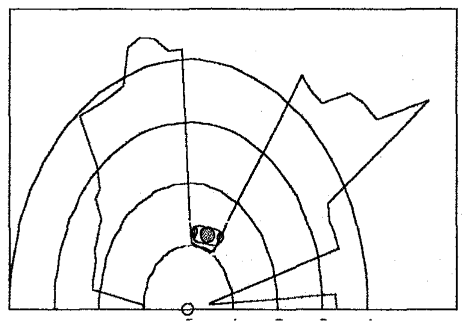


180° range / angular resolution = 2°

Fig.13 Linguistic labeling

attention mechanisms increase the resolution at a particular orientation or distance range to split de correspondent representation set. These mechanisms allows "situated knowledge" (Agents), to be continuously updated to the current goals, environment requirements, and sensing-acting capabilities .

This low precision, but high flexible domain friendly cooperates to perform a rule-based sensor fusion methodology based on human experience and on the multiple and different low cost transducers information.



meters

Fig. 14 Human body detection by the U.S. scanner

In Fig.14, one of the authors stands up at 1m. in front of the rotating sensors team, being perceived as the figure shown by the ultrasonic image at regular 4° angular intervals.

The same obstacle is also seen as a shadow to the backlight window by the color sensing devices, Fig.15. The existing relationship between the local minimum in both images is clearly highlighted.

However, the correspondence problem between this two perception subsystems is not an easy issue from an analytical point of view. Relative position among the light sources, the possible obstacles, the surrounding objects and the receiving device can create a non affordable states space.

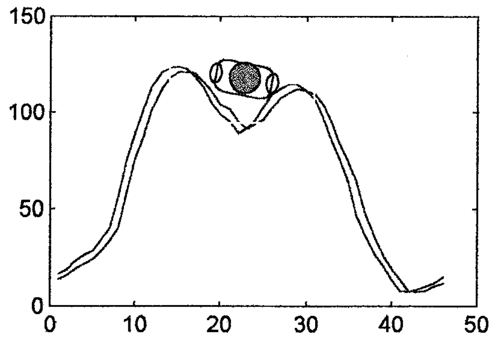


Fig. 15 Shadow perception of the same obstacle

A fuzzyfication process for these sensory maps allows for simple linguistic descriptions of "situated spatial links" [10]. Therefore, a high light intensity region corresponds to a window area, a local minimum located in such region would probably be associated to an opaque object in between the light source and the sensing system. The minimum distance encountered by the ultrasonic beam echoes also detects an obstacle that can be located "close" and "in front of" the receiver.

Consequently, a few simple rules, close to human experience and linguistic expressions, link the "opaque object" which shadow is perceived by the light scanner to the ultrasonic echoes minimum distance region. The description of expanded capabilities or changing environments can be updated by either adding new inference links or deleting already despaired relationships, without greatly disturbing the overall architecture.

6. CONCLUDING REMARKS

The proposed distributed architecture offers the modularity and scalability required for autonomous robots in dynamic and unpredictable environments.

Active Perception mechanisms can be accounted for at the very low abstraction level close to the physical sensors, as the unconscious robot level.

Well-fitted low level behaviors at the microcontrollers programmable level can be frozen in high speed, low cost hardware devices, as FPGA's, to attain critical real time requirements.

Fuzzy logic representation allows for an easy translation from the heuristic expert knowledge, linguistically expressed, to the low level control commands.

7. ACKNOWLEDGMENTS

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