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SENSORS FOR ROBOTICS – ADVANCING QUALITY TOOLS

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Current status and future prospects of robotics for the service of humanity are outlined from the standpoint of sensor technology. The use of the robot for the service of humanity needs new technologies which are categorized as the third generation robotics. Sensors for manipulation, locomotion and man-robot systems toward the third generation robotics are discussed.

KEYWORDS:
Intelligent Robot, Third Generation Robotics, Mobile Robot, Man-Robot System, Tele-existence.

1. Introduction

Although the word "robot" is of recent origin, since 1921, when Czechoslovakian playwright Karel Capek coined the word from the Czech word for "worker" in his play R.U.R., the concept of the robot *per se* is quite old, at least as old as recorded history. We see, for instance, in Iliad of 8th century B.C. two female statures of pure gold which assisted Hephaestus, God of all mechanical arts. Talus, the giant made of brass, which was told to guard Crete against all intruders as another example of the everlasting human dream for perfect slaves.

It was, however, merely a matter of legend or fiction and realized only as a toy for a very long time. After World War II, as cybernetics and automation technology progresses, it between the robot and the human, which lead to the superb control and accomplishment of the tasks in the unstructured environment.

Figure 1 summarizes the author's classification of the generations of robots and their features.

3. Sensor for Manipulation

3.1. Tactile sensors

Some assembly tasks can often be accomplished with little or no sensing of events in the environment. RCC (Remote Center Compliance) device developed at the C.S. Draper Laboratory [D.E.Whitney and J.L.Nevins, 1979] is a typical example that demonstrated that some insertion tasks can be done by intrinsic sensing and actuating function of specially designed mechanisms.

For more complicated tasks and/or manipulation tasks with little *a priori* knowledge, tactile sensing capability is thought as most fundamental sensing function of robots, for it is the interface or interaction point between the internal world and external world of the robot.

Compared with visual sensors (CCD, CID, MOS image sensor, etc.) we have no general sensors for taction. Research and development are being done seeking for tactile sensor like human skin and force sensors like human tendon organs.

3.2. Visual sensors

Visual sensors became practical first in the industrial inspection tasks, e.g., several quality control systems for printed circuit boards and integrated circuits. Inspection techniques are applied to the assembly as wire-bonding system, e.g., transistor wire-bonding system using binary template matching method by Hitachi [S.Kashioka et al., 1976].

An assembly experiment was performed in the AI Laboratory at Stanford. The vision system identifies various components e.g., the housing, gasket, and rotor assembly of a water pump. Similar assembly research has been performed in AI Labs at M.I.T., Edinburg University, S.R.I. International, Osaka University, Mechanical Engineering Laboratory in Japan, and in a number of industrial laboratories including IBM, Westinghouse, General Electric and Hitachi.

Use of laser and position sensitive detector (PSD) in arc welding robot by Mitsubishi [T.Bamba et al., 1981] is another example of the success in usage of visual sensors.

The main features that make the visual system successful in manufacturing factories are (1) appropriate illumination techniques including spot or plane projection method to get recognizable picture, (2) binary techniques and (3) special hardware for real time picture processing.

More general visual systems are being investigated for use other than in manufacturing factories.

4. Sensors for Locomotion

Studies on locomotion in robotics are relatively at the primitive stage compared with the manipulation. This is because robots were first used in factories where robots usually had not to move. All parts are carried by special systems like conveyors.

Next generation robots definitely need locomotion capability, which can only become possible through the use of new sensors and information processing techniques for locomotion.

For the control of legged mechanisms, which will be of great importance for versatile mobility like stair climbing, internal sensors like gyro are extensively used in addition to the tactile and visual sensors [R.B.McGhee and G.I.Iswandhi, 1979].

Navigation and obstacle detection/avoidance are two crucial problems to be solved in the control of locomotion system in the wide area where it is supposed to work.

Fundamental experiments for the above two problems have been made by the author and his colleagues [S.Tachi et al., 1981a, 1981b, 1982, 1983, 1984] in the Guide Dog Robot project (MELDOG). MELDOG project intends to enhance mobility aids for the blind by providing them with the functions of guide dogs, i.e., obedience in navigating or guiding its blind master, intelligent disobedience in detecting and avoiding obstacles in his path, and superb màn-machine (animal) companionship or communication. It can independently travel from one place to another using a city map with specified landmarks stored in the memory of the robot and the obstacle information gathered by the sensors on board the robot.

Figure 2 shows the schematic diagram of the guide dog robot MELDOG system and Fig. 3 shows general view of outdoor experiment with the test hardware MELDOG MARK IV.

Similar experiments of navigation and obstacle avoidance are being performed at LAAS in France [G.Giralt et al., 1983] and at CMU and Stanford [H.P.Moravec, 1983] in U.S.A.

Future problems are (1) structurization of the unstructured environment, (2) selection, structurization, and effective use of natural landmarks and (3) more intelligent obstacle detection and real time avoidance.

5. Sensor in Human-robot System

A typical potential usage of the third generation robot is to liberate human from the works in potentially hazardous working environments. These include, for example, work in nuclear plants, undersea operations and rescue operations in disaster area.

A robot system which will be used in these works will be the human-robot system that consists of several mobile intelligent robots, supervisory control sub-system, a remote operator and communication sub-system between them.

Figure 4 shows the author's concept of human-intelligent robot system to cope with those critical work under hazardous working envior nment.

Planning, scheduling and task sharing by plural robots are handled by the supervisory controller [T.B.Sheridan, 1976], while each robot consecutively sending progress report of the work to the supervisory controller.

The reports are compiled and processed by the supervisory controller and selected information is transmitted to the operator through visual, auditory and tactual channels. The operator gives macro commands to each of the robots via voice recognition device.

When a intelligent robot is confronted with the task which is beyond its own capacity, the control mode is switched to the highly advanced type of tele-operation called TELE-EXISTENCE.

Tele-existence technology, which is being investigated by the author and his colleages [S.Tachi et al. 1984], tries to enable a human operator at the controls to perform remote manipulation tasks dexterously with the feeling that (s)he exists in the slave anthropomorphic robot in the remote environment.

How can we display a realistic scene to the operator ? How can we maintain the relation between an object and the robot's upper extremities (arms and hands) at the remote site to have sensation of presence ?

Figure 5 (I) shows the traditional concept of three dimensional display. All waves coming into a robot at the remote site are recorded at ideally infinite points on a closed surface enclosing the robot. These recorded waves are transmitted and played back in real time at the corresponding points on a surface enclosing the operator.

The above method of wave reconstruction has the following disadvantages:

(1) It is difficult to make an enormous recording and play back system which encloses a robot or operator, and results in a small display with a lack of realistic feeling.

(2) When an operator tries to handle an object, (s)he sees both robot's upper extremities and his/her upper extremities, thus it is difficult to avoid the feeling of remoteness.

Figure 5 (II) shows a new type of display using robot technology. This is based on the principle that the world we see is reconstructed by the human brain using only two-dimensional pictures on the two retinae changing in real time according to the movement of the eyeballs and the head [S.Tachi et al., 1984].

In a new type of robotic display,

(1) Human movements incuding a head and eyeballs are precisely measured in real time,

(2) Robot sensors are constructed anthropomorphically in function and size,

(3) Movements of the robot sensors are controlled precisely to follow the human operator's movement, and

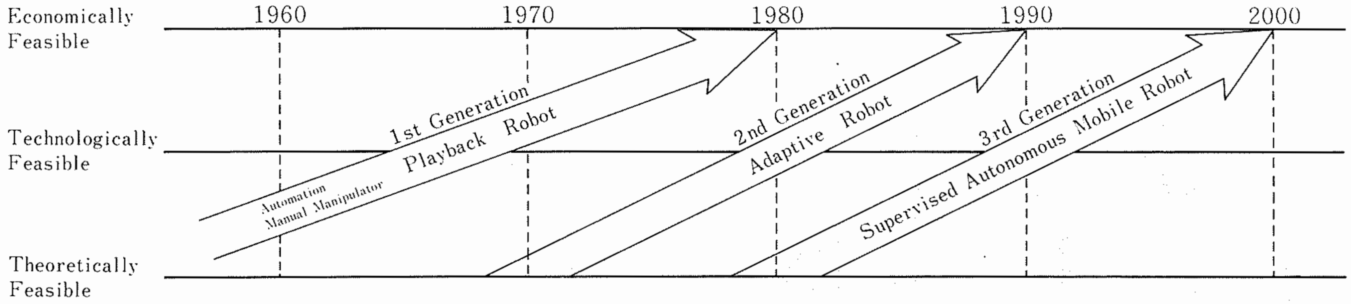
(4) The pictures taken by the robot sensors are displayed directly to the human eyes in a manner which produces the feeling of presence.

Figure 6 shows an experimental system of the visual display with sensation of presence.

Again mesurement and control technology are expected to play an important role in the development of the technology necessary for the human-robot system.

6. Conclusions

The last two decades have witnessed a worldwide effort to realize robots for manufacturing factories. The use of the robot for the service of humanity needs the third generation robot technologies, which can be made possible by the extensive study of measurement and control. Above all sensors will be of vital importance for the next generation robot.



		1st Generation	2nd Generation	3rd Generation
Brain Fnnction	Intelligence	a priori [inborn] (play back)	adaptation, accomodation	a posteriori [acquired] (learning, inference, problem solving)
	Knowledge	data	date base	knowledge base
Sensor Function	Internal Information	exist	exist	exist
	External Information	none or point	1−D, 2−D (structured environment)	3−D (unstructured environment)
	Communication	unilateral (teaching, tape)	interactive (robot language)	bilateral (supervisory control, tele-existence communication between robots, natural language)
Effector Function		position control (static) 1−D (guide cable)	position control (dynamic) 2−D (plane guided)	force control (dynamic) 2−D (uneven autonomous) ;3D (stairs free space)
Application Fields		Secondary Industry (Manufacturing Industry) [Material Handling Painting Spot Welding]	Secondary Industry (Manufacturing Industry) [Arc Welding Assembly]	Secondary Industry (Non-Manufacturing Industry) Primary Industry Tertiary Industry

Fig.1 Robot generations and their features

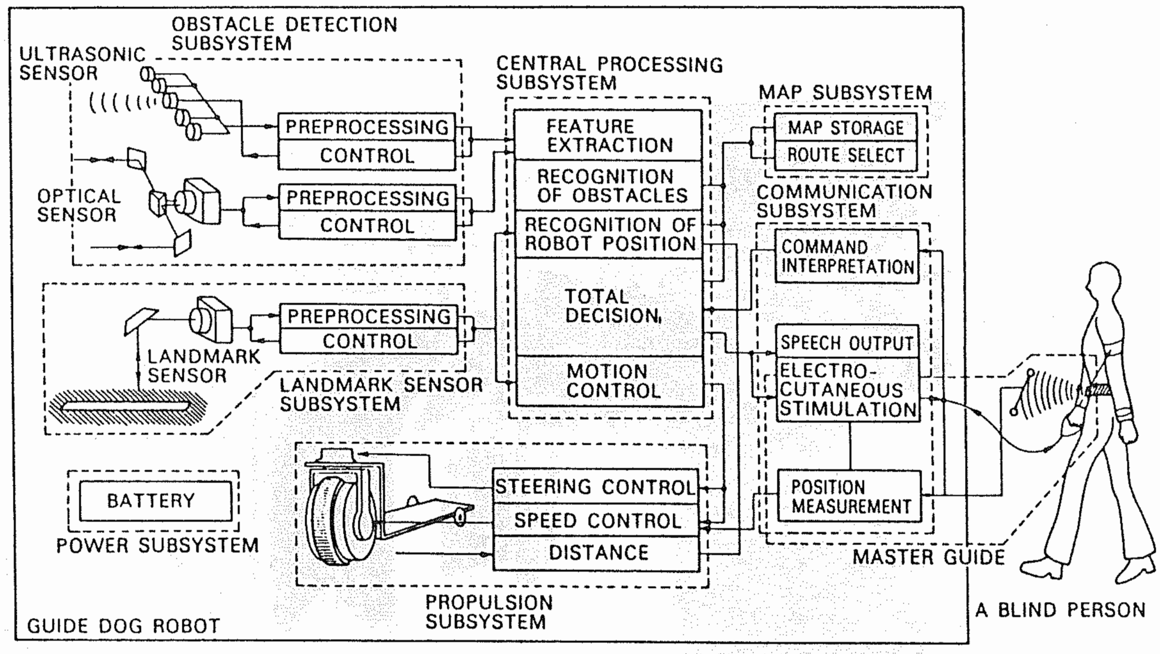


Fig.2 Schematic diagram of the guide dog robot system (MELDOG)

Fig.3 General view of the guidance by MELDOG MARK IV

EU : Environment Understanding
D : Decision
LP : Language Processing
MC : Motion Control
SIP : Sensory Information Processing
KDB : Knowledge Date Base
SA : Situation Assessment
MU : Mission Understanding

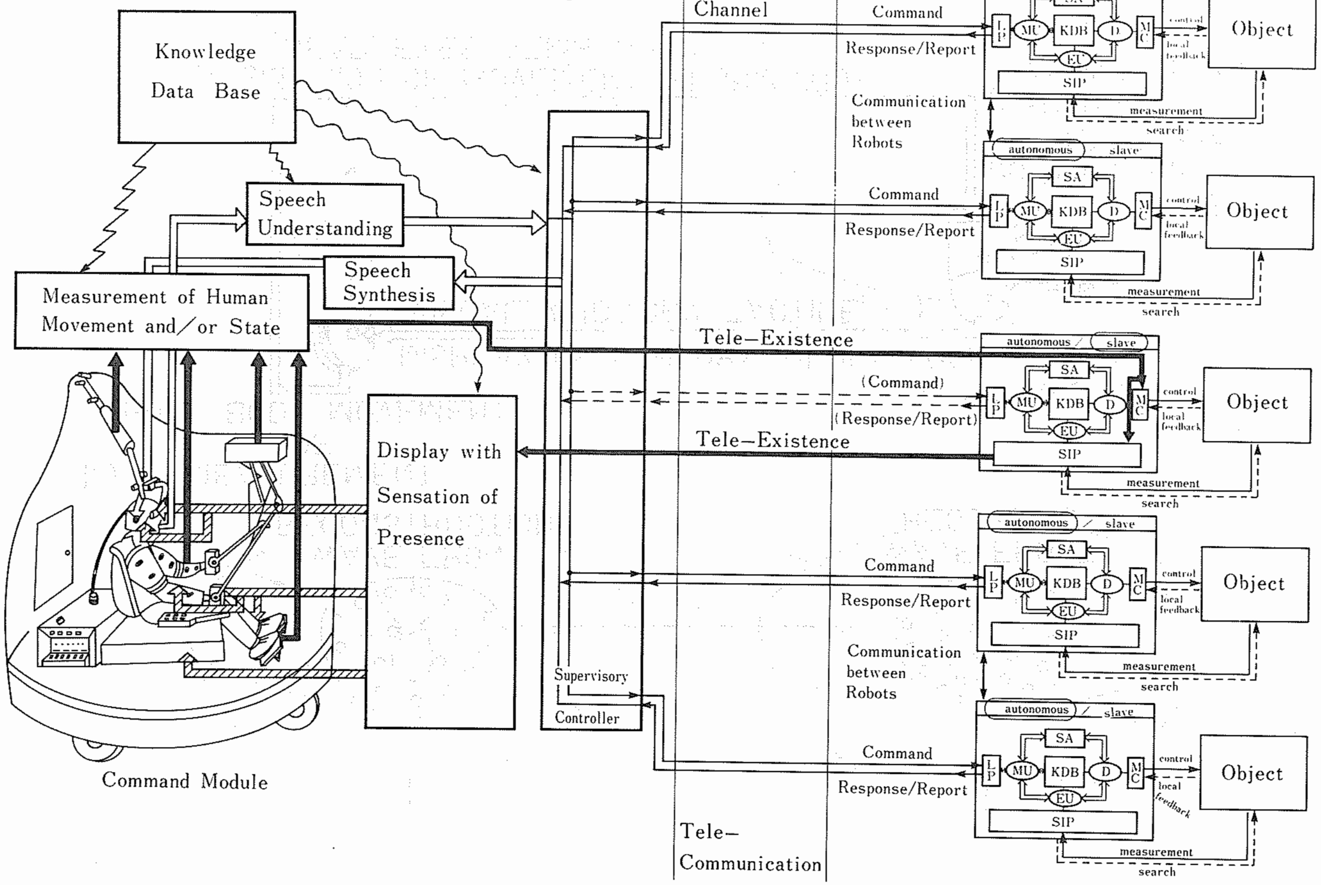


Fig.4 Schematic diagram of the man-robot system being studied

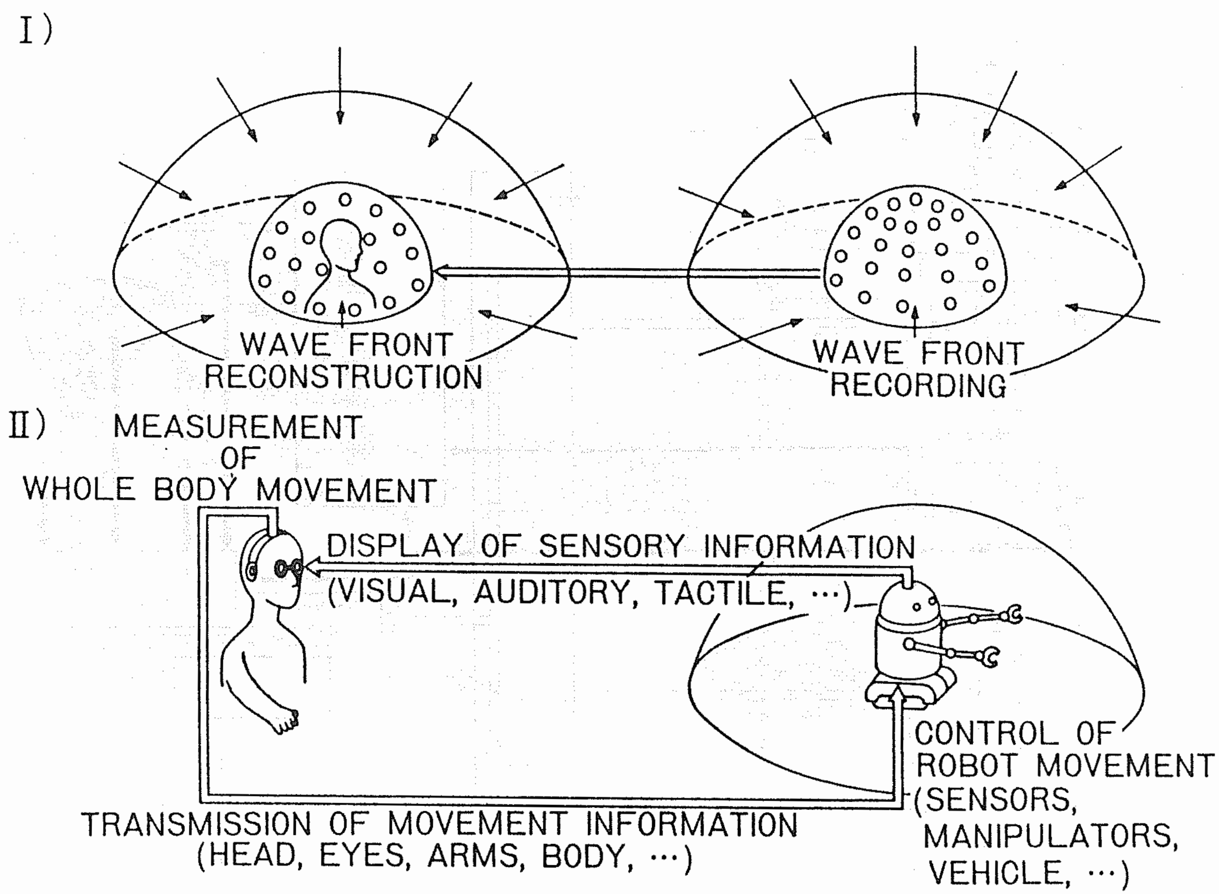


Fig.5 Concept of wave front reconstruction display (I) and tele-existence display (II)

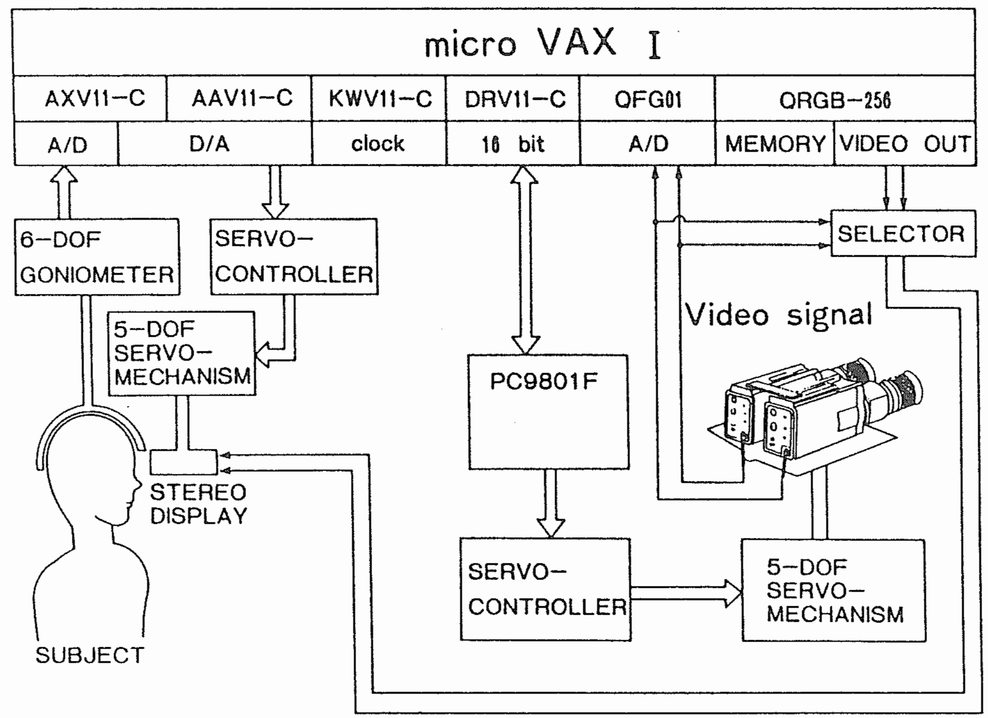


Fig.6 Schematic diagram of the experimental display system with sensation of presence