by Fumio Harashima and Satoshi Suzuki

State-of-the-Art Intelligent Mechatronics in Human–Machine Interaction

Intelligent mechatronics is a machine system that has its own entity and equips humanlike or creaturelike smart abilities. The concept of intelligence is, however, ambiguous; hence, there is no clear definition because the meanings and nuances are modified according to the individual intention of a designer who deals with the concept. In this column, the characteristics and system structure of intelligent mechatronics are briefly mentioned. Several types of state-of-the-art intelligent mechatronics, such as communicative, network, human-assistive, and cognitive types, are introduced.

Properties of Intelligent Mechatronics

Intelligent mechatronics basically consists of an electronics mechanism unit and an information processing unit for control of motion. Hence, it is inadequate to call a virtual agent by computer graphics intelligent mechatronics without the physical body. Intelligent mechatronics is designed with consideration for dynamic change of the environment, humans, and events. To cope up with these exogenous factors, the usual intelligent mechatronics has the processors of perception–cognition–motor and information storage like the model human processor (MHP) [1], shown in Figure 1. To adapt to dynamically changeable factors, a module-based architecture like the National Aeronautics and Space Administration (NASA) standard reference model for telerobot control system architecture (NASREM), which will be shown in the section "Cognitive Intelligent Mechatronics," is a fundamental method for intelligent mechatronics. The functions in most types of intelligent mechatronics are modularized, and those modules are implemented as a hierarchical system structure. The categories and types of intelligent mechatronics appear to be classified depending on their functions and system structure. In the following sections, the representatives of intelligent mechatronics are introduced.

THE ROLE OF INTELLIGENT MECHATRONICS IS TO ENHANCE HUMAN INTELLIGENCE BY MECHATRONICS SYSTEMS.

Communicative Intelligent Mechatronics

Communicative intelligent mechatronics is one of the human–machine interfaces, but this is quite different from a mere information terminal, since the entity of the utterance exists with the body of mechatronics. A simple example of communicative intelligent mechatronics is verbal communication. A mechanism to understand the dynamics of communication is a key factor. The applied examples using the recurrent neural network and interactive evolutionary computing [2] are known. Recent research on nonverbal intelligent mechatronics is active. Since nonverbal communication can induce strong mental interaction from a human, socially intelligent mechatronics, or so-called therapy robots, have been developed. For instance, the seal robot Paro [3] was created to attempt to improve the

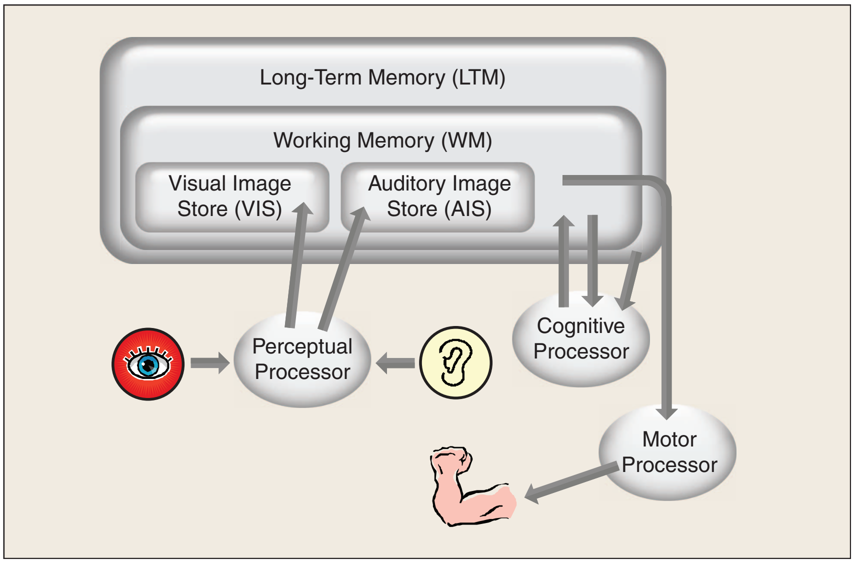

FIGURE 1 – The MHP.

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FIGURE 2 – The seal robot, Paro, was created to improve mental health in elderly patients (image provided by T. Shibata, AIST, Japan).

FIGURE 3 – The PDBR (image provided by K. Kosuge).

physiological and psychological health in elderly patients (Figure 2). The social/sociable robots such as Kismet and Leonardo were developed to study the cognitive–affective architecture based on the embodied cognition theories such as the theory of mind, mind reading, and social common sense [4]. To equip the machine with this kind of intelligence, not only the sophisticated motion control of the machine body but also the mathematical mental model is required (for instance, [5]). Other types of this intelligent mechatronics are the eye-contact robot [6], the face direction and pointing behavior [7], the joint attention [8], the conjugate gaze [9], the nod [10], and the facial expression [11]. Any of these approaches try to communicate intuitively and instantaneously.

Physical interaction using reaction force on a cooperative task appears to be a nonverbal communication that is peculiar for mechatronics, although this is not strictly nonverbal communication in the customary sense. Since one of the topics of research for adaptive intelligent mechatronics is to read a human's intention, a partner ballroom dance robot (PBDR) was created (see Figure 3). The PBDR estimates the intention of a human dance partner from the force-sensor information, selects the adequate dance step, and generates its own motion [12]. Such technologies of the collaborative control based on the mechanical interaction and adaptive motion planning involving the estimation of human intention are expected

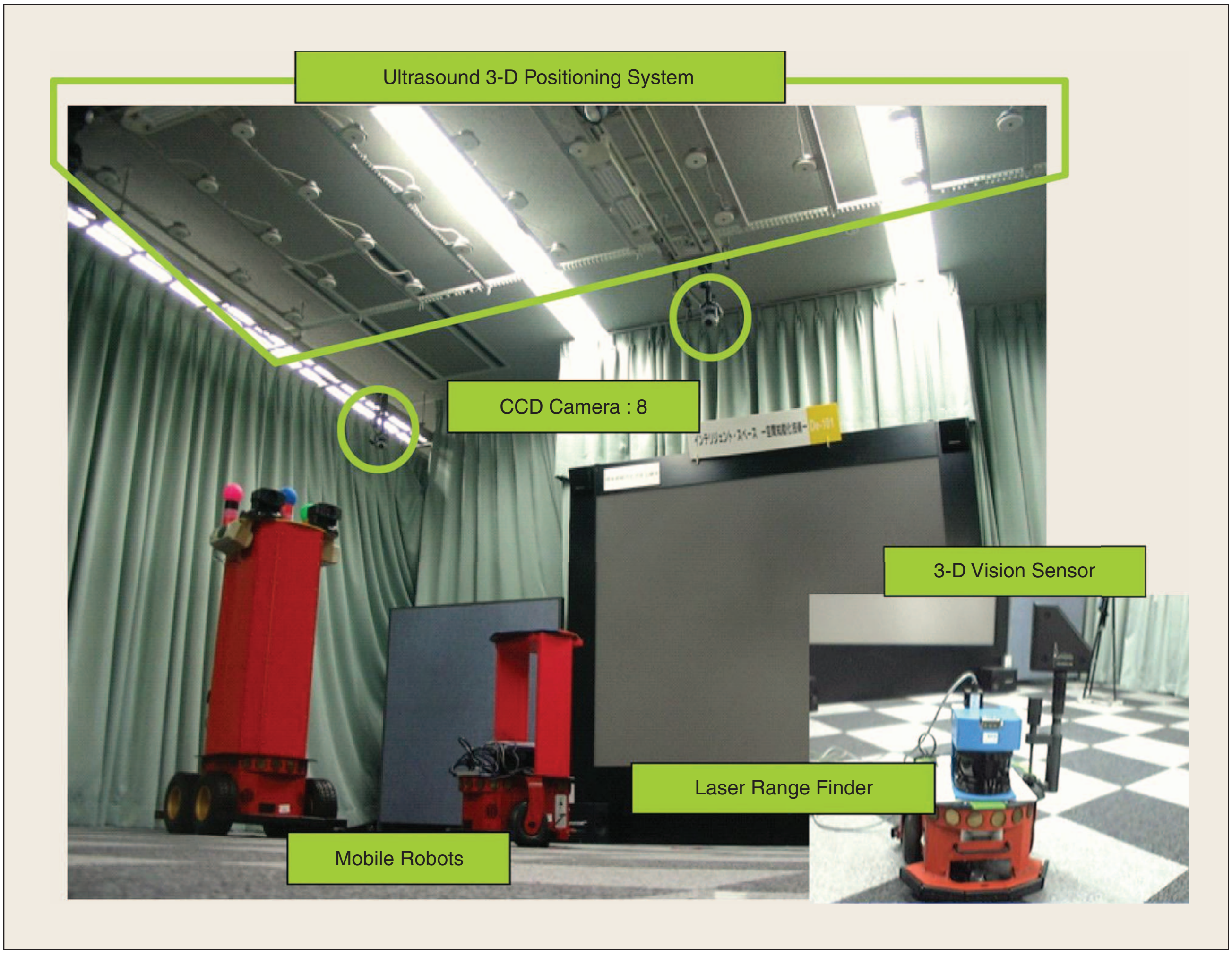

FIGURE 4 – Network intelligent mechatronics: Intelligent space (image provided by H. Hashimoto).

for advanced communicative intelligent mechatronics.

Network Intelligent Mechatronics

The purpose of network intelligent mechatronics is the realization of high performance by integrating information. This type is often called a networked robot. The difference between other information integration system and intelligent mechatronics is that sensor nodes of the intelligent mechatronics are movable by the mobile platforms like wheeled mobile robots. Both the environment of the work area, including the infrastructure, and the robots have to be adequately designed. Since this type of intelligent mechatronics is already equipped with the network for communication with other mobile nodes, extension of the local network to the Internet enables us to realize a new type of network robot termed as network intelligence or Web intelligence [13]. In Japan, three types of network robots were proposed: virtual, unconscious, and visible [14]. The virtual type is an agent or an icon robot in virtual space to communicate with a human. The unconscious type is embedded in the environment and detects both human action and circumstance by various kinds of sensing technology. The visible type is a conventional robot that works in actual space. This type of intelligent mechatronics is studied actively in many countries: the ubiquitous robot companion in Korea and networked robots in Euro-America. The ubiquitous networking robotics in urban settings (URUS) project in the European Union [15] is promoted as a field-test research. One illustrative case is intelligent space [16], which makes the whole space of the room intelligent by using sensors distributed in the room and mobile robots (Figure 4). The Intelligent Room project [Artificial Intelligence Laboratory at Massachusetts Institute of Technology (MIT)], DreamSpace (IBM), and Oxygen project (MIT) [17] were similar studies of research; however, these approaches did not consider the physical interaction between robot agents and humans. Studies of network intelligent mechatronics can be interpreted as a challenge to create a fusion of mechatronics workspace and human everyday space.

INTELLIGENT MECHATRONICS BASICALLY CONSISTS OF AN ELECTRONICS MECHANISM UNIT AND AN INFORMATION PROCESSING UNIT FOR CONTROL OF MOTION.

Human-Assistive Intelligent Mechatronics

In recent studies, the enhancement of human abilities by a machine has been taken into account, considerably. Many international research projects based on such a policy have been continued.

In the German Anthropomorphic Assistance Systems (MORPHA) project, the communication and interaction with intelligent robot assistants were treated. The project focuses on the coexistence of the human and robot in housekeeping and manufacturing [18]. In the European cognitive robots companions (COGNIRON) project, robot companions to exhibit cognitive capacities have been studied for human-centered environments [19]. In the Japanese human adaptive mechatronics (HAM) project, the analyses of human skill and the establishment of assisted methods for human operators are the main concerns [20]–[22]. HAM is aimed at assisting the human according to his or her skill level by changing their own functions. The surgery-support system (scrub-nurse robot system) [23] (Figure 5) has been studied as an application of HAM. The safe manual control [24] and the rate saturation control of actuators [25] were proposed as theories for HAM. Skill analyses by monitoring the brain with the near-infrared spectroscopy in the mirror-drawing test [26] and the virtual pendulum stabilization task [27] have been continued. To cope with human factor skill, the informatics, cognitive psychology, brain science, sociology, and biology are required; hence, system integration studies including these specialities are expected for progression.

Cognitive Intelligent Mechatronics

Cognitive intelligent mechatronics differs obviously from an existing environmental discrimination based on only passive observation or a

FIGURE 5 – Scrub-nurse robot system (image provided by F. Miyawaki).

classical artificial intelligence that is built only by a computer database. The embedded algorithms are designed mainly by referring various human cognitive models. Norman's seven stages of action [28] and Rasmussen's three levels of skilled performance [29] provide us with useful information. For the control algorithm and its implementation, the representative approaches are as follows with relation to these models:

- sequential processing of perception–decision–action (Norman's modellike approach)
- top–down hierarchical control mechanism (Rasmussen's modellike approach)
- bottom–up hierarchical control mechanism [subsumption architecture (SSA)].

> **THE PURPOSE OF NETWORK INTELLIGENT MECHATRONICS IS REALIZATION OF HIGH PERFORMANCE BY INTEGRATING INFORMATION.**

The first approach is the so-called classical artificial intelligence, and this is often used in practice because of the simplicity of the algorithm. There is, however, a limitation known as the frame problem where exception processing has to be programmed adequately beforehand against the dynamical domain. The second approach has a hierarchical structure with multilayers corresponding to the complexity of the knowledge and intelligence that are required to perform an actual task. NASREM [30] by Albus and the multiresolutional control architecture by Meystel are such representatives [31]. In NASREM (Figure 6), a common memory stores information of the model of an external world and provides the information to each module. This module assigns the task, makes the plan, and executes the task at each layer. The world-modeling module plays a role of the so-called internal model, and the predicted value is computed and passed to other modules.

The third approach, SSA, was proposed by Brooks. Action of the machine is changed reflexively by an interaction to the environment without an explicit model of the environment. SSA is not adequate to the complex task that requires ratiocination or communication, since SSA does not have the model of the inner and outer worlds. Despite these, this mechanism produced a marked impression compared with orthodox artificial intelligence, because SSA has a counterbalancing ability to the frame problem, at least in principle.

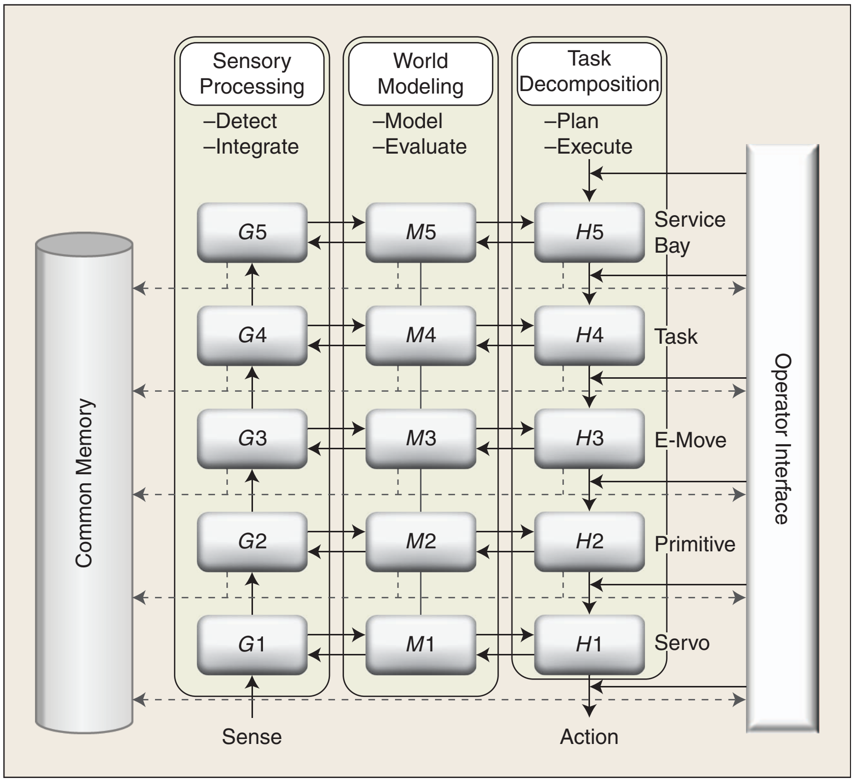

FIGURE 6 – The NASREM.

Recently, affordance theory has attracted attention, and a behavior design of robots based on affordance concept has become an active research area. There are two kinds of definitions about affordance in a precise sense, and Norman's affordance is frequently cited in the context of human–machine interaction [28]. The definition of affordance is the action possibility and an opportunity given by an environment to the creature that lives there. For instance, a human involuntarily changes his or her hand's shape according to the difference of the handle type of the door and changes the direction of the hand motion accordingly. An intelligent mechatronics designed using an affordance theory extracts information that is implicitly embedded in the environment and selects the final action from several action possibilities based on the information [32]. Such intelligent mechatronics is a new type that adapts to the environment by using human instinctive/existential properties, and it holds the possibility of a development for future cognitive mechatronics.

Epilogue

Various studies with keywords "intelligent mechatronics" are active. The completeness of the quality is, however, still insufficient compared with the human intelligence. The reason is that knowledge of human psychology cannot be written sufficiently by computer algorithms; hence, the present intelligent mechatronics cannot understand the human perfectly. The role of intelligent mechatronics is to enhance human intelligence by mechatronics systems. The authors hope that this will happen in the not-too-distant future.

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Biographies

Fumio Harashima worked as a professor from 1980 to 1998 at the University of Tokyo, Japan. He served as a president of the IEEE Industrial Electronics Society from 1986 to 1987 and as an IEEE secretary in 1990. In 1995, he served as a founding editor-in-chief of *IEEE/ASME Transactions on Mechatronics*. He has been a professor emeritus of the University of Tokyo since April 2000. From 2004 to 2008, he served as president of Tokyo Denki University, and he is currently the president of Tokyo Metropolitan University. He has received a number of awards, including the 1984 IEEE/IES Anthony J. Hornfeck Award, the 1988 IEEE/IES Eugene Mittelmann Award, and the IEEE Millennium Medal in 2000. He is a Fellow of the IEEE.

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