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Aspects of Japanese Robotics Research

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Robotics appears to be a very lively and fruitful field of research in Japan. Some of the research topics cannot be found elsewhere at all, and some are significantly advanced. Discussing this impression, a collection of laboratories is introduced with their most outstanding topics.
This report is based on the notes of trips through Japanese laboratories in February, September 1997, and January 1998 as well as on long term research relationships with Japanese institutes.

1. Motivation and Criteria

The robotics research scene in Japan is a widespread and lively community. From this scene, research topics and projects that are unique or original will be highlighted. This report is not meant to be a strict scientific discussion of the subjects, but to set a spotlight on recent trends and developments in the Japanese robotics research community and to give links for deeper investigation.

Criteria used for the description of groups and projects include:

- Original and outstanding research topics.
- Basic research issues.
- Disciplines represented in the group, thus the interdisciplinarity of the group – a key issue for most parts of robotics research.
- International exchange (visiting researchers).
- Intended or implemented applications.
- Industrial relationships.
- Participation in research funding programs.
- Organisation or initiation of conferences, workshops, and scientific organisations.
- Special aspects / notes.

The discussed groups and projects are a selection of the laboratories known or have been visited by the authors only. Thus this report focuses on some recent work instead of listing the full range of robotics groups. Up to now, there are more than 150 Japanese research groups concerned in robotics research or closely related topics [20]. And even in this listing the 'classical' control theory oriented stream of robotics, mainly relating to manufacturing manipulators, is not covered completely.

The description of individual laboratories is organized in three sections:

- Biological orientation: The motivation to understand biological creatures and to mimic certain observed aspects is a central issue in these laboratories. Biologically plausible solutions are usually preferred over technologies, exploiting global observers or high speed communications.
- Learning & cognition: Here the understanding and design of artificial creatures is the central aspect. Especially adaptability to current working environments as well as the understanding and modelling of complex interactions between robots themselves and with their habitat is discussed.
- Mechatronics: By studying the complex possibilities of kinematics with many degrees of freedom and understanding high speed feedback systems, a third important aspect of robotics research is addressed.

These categories are anything but rigid. The selection being done here is based on the main motivation of each group. Obviously, solutions originating from investigations in many degrees of freedom kinematics can also be biologically plausible.

The authors are aware of the fact that the selection of 'interesting' topics is to a certain degree related to the research focus and background of themselves. Thus the robotics research activities of the authors should be mentioned briefly by keywords: *Autonomous systems* [18] (especially mobile systems in natural environments), *learning and adaptation* [19] (on all levels of control / cognition), *complete systems* [2] (i.e. 'closed loop' systems), and *complex behaviours* [7], (together with fruitful experimental setups evaluating these behaviours).

2. Biologically Oriented Laboratories

Working with biological creatures (laboratory of *Hirofumi Miura* and *Isao Shimoyama*), mimicing biological systems (*Noboru Ohnishi* laboratory and the laboratory of *Masami Ito*), organizing robotics groups under biologically plausible aspects (the biochemical systems laboratory of *Isao Emura*) or observing human teachers and try to replay and refine recognized actions (*Mitsuo Kawato* laboratory) – these are all aspects of biologically inspired robotics research. Two of these laboratories will be discussed here.

2-1. Miura & Shimoyama Laboratory
University of Tokyo

The laboratory of Hirofumi Miura and Isao Shimoyama at the University of Tokyo handles a range of disciplines under the aspect of some well-defined leading topics. Insect behaviours, biological sensors, µ-robotics, and 'combinations' of biological and mechatronic creatures are some of the topics the laboratory is dedicated to. Strong backgrounds in biology (also in cooperation with the group of Ryohei Kanzaki at the University of Tsukuba), µ-mechanics and µ-electronics, as well as computer science are available. Moreover the team is internationally oriented. Fabrizio Mura for instance (coming from the laboratory of N. Franceschini at the CNRS, Marseille, France) performs research on an insect compound eye design and Raphael Holzer (from Switzerland) experiments with stimulated cockroaches and other setups [8].

The authors would like to discuss only some aspects out of the research field of the Miura and Shimoyama laboratory briefly: The first aspect is µ-robotics, where ideas from Japanese Origami are joined with sophisticated µ-mechanics, leading to walking machines of 0.7 by 1.5 mm . The energy problem is solved by stimulating oscillations of mechanical parts externally. These mechanical resonances (at 50 and 100 Hz) are used to activate a pushing leg on each side of the vehicle. By using different resonance frequencies on each side, the direction of motion is controlled also. As other sources of energy for the µ-manipulators, structures sensitive to magnetic, electrostatic [8], and air pressure changes are presented. All these parts are produced in two cleanrooms owned by the laboratory.

One of the projects including biological components is the usage of a pheromone sensitive antenna extracted from a silk moth for the control of a small mobile robot. It could be shown that this biological sensor can be employed successfully to follow a track of pheromones by an artificial creature [10]. Recurrent neural networks and genetic algorithms are employed also in the development of motion control structures.

In a further experiment cockroaches are stimulated by electrical pulses and heat at some sensitive areas in order to control their walking behaviour. The complete µ-controller as well as the energy and the I/O for this task are applied on a small 'backpack' for the cockroach. Some potential applications are inspections after an earthquake, where cracks or pipes are often too small or rough to use conventional robots. In another experiment individual cockroach legs are extracted, stimulated electrically and attached to an artificial body. Here the movement control is more explicit (and thus complex) than by stimulating the whole insect to move towards a certain direction.

The other way round, a robot controlled by a (completely intact) silk moth in order to follow a pheromone track is also implemented successfully. Being fixed over a conventional trackball, the moth controls the robot by turning the trackball with its feet.

'Conventional' robots, like a six-legged robot are used also to study the generation of walking patterns. Two walking robot designs (in the 'standard scale' mechanics) were produced in the laboratory for this purpose up to now.

Finally a flying µ-robot is presented, where a magnetic sensitive layer (nickel) is used in conjunction with polyimide to produce a wing-flapping movement, controlled by a magnetic field [13].

2-2. Kawato Laboratory
ATR, Kyoto

The group of Mitsuo Kawato as part of the ATR (Advanced Telecommunications Research Institute International) and as part of the ERATO project, is dedicated to investigations in the sensor-motor loop of biological as well as artificial creatures. International contacts are intense and many visiting researchers are participating in the research (49 out of 224 researchers at ATR are invited from overseas). In the group of Mitsuo Kawato for example, which is part of the human information processing laboratory, Stefan Schaal – a visiting researcher from Georgia Institute of Technology – was heading the computational learning group in the Kawato Dynamic Brain project (ERATO).

One of the approaches followed is an observing and rehearsal method, where complex sensor-motor tasks like Kendama (a Japanese game), pole balancing and others are performed by human 'tutors' and observed by a stereo camera system. This recorded information is used to initialize a kinematic model that is refined during further process by reinforcement learning methods. Thus the search in the tremendous spatio-temporal state space of a seven degrees of freedom arm (here especially constructed for this experiments using fast hydraulics) is significantly pruned in order to make the learning task efficient.

The work could be demonstrated in practical experiments starting from the observation of the human tutor to the learned pole balancing. The theoretical foundation of the 'bi-directional theory' can be found in [11]. Here the central aspect is that the exchange of coordinating control information between higher and lower level components is forced in both ways and that modules are operating in parallel. Details about the reinforcement learning scheme can be found in [3] given by Kenji Doya who is the head of the computational neurobiology group.

In cooperation with Hiroaki Gomi from NTT Basic Research, the human reactions to small disturbances during the movement of a handle in a two dimensional plane are recorded. Measuring the stiffness and other parameters of a human arm during such a movement, the relationship between local reflexive control and overall control by the brain is investigated. Experimental results imply that explicit and continuous control by the brain is playing a more important role than assumed up to now [5].

3. Learning & Cognition

The process of adaptation, learning and cognition as understood as situated interactions and modelling of dynamical environments is discussed as: a principle of autonomia in organisms ('Ba' research institute of *Hiroshi Shimizu*), a dynamical system (research conducted by *Jun Tani* at Sony CSL), learning of elementary and complex behaviours with little a-priori knowledge (laboratory of *Minoru Asada*), a process of visual sensing (laboratory of *Yoshiaaki Shirai*), a cooperative system including many types of agents (laboratory of *Toyoaki Nishida*), an interaction of robots and humans in natural environments (Real World Computing (RWC) group header by *Nobuyuki Otsu* at ETL), or as imitation and social behaviours (group of *Yasuo Kuniyoshi*). To highlight just two of these directions, SONY CSL and the group of Yasuo Kuniyoshi will be discussed briefly.

3-1. Sony Computer Science Lab.
Tokyo

The laboratory headed by Mario Tokoro has strong international relations in most fields of computer science. International researchers are regularly invited to the laboratory and support a dynamic and lively group atmosphere. Robotics research is conducted by Jun Tani, in collaboration with Chisato Numaoka (now moved to the Paris dependence of Sony CSL) and Luc Steels from the University of Brussels (VUB), who has visited the laboratory several times. The laboratory is in existence for almost ten years, and has settled on many advanced (basic) research areas.

Involved robotics topics are vision, dynamical systems (implemented in recurrent neural networks), dynamical world modelling, concept formation (symbol generation), and active vision. The first experiments are performed with a mobile robot equipped with a laser range finder. The robot wanders in a maze like environment and detects branches. The sequence of branches, i.e. the time sequences of the data delivered from the laser range finder is used to train a recurrent neural network with internal states, representing the context [14].

The work is currently expanded to more complex concepts of the environment using a vision system on a new mobile robot with some possibilities of interaction, due to a two degrees of freedom arm. Topics like attention mechanisms and active sensing are considered too. Up to now it could be shown that a spatio-temporal world model can be generated and interpreted as a dynamical system where unbounded series of sensor samples are employed – thus a calibration of the system is not being done by introducing absolute landmarks (or similar information) in advance, but by interpreting the structures in the generated phase-space of the dynamical system.

A recent research stay of Stefano Nolfi at SONY CSL led to an approach of hierarchical recurrent modules, which scales much better in complexity than other or former recurrent systems [15].

3-2. Kuniyoshi Laboratory
ETL, Tsukuba, Ibaraki

The laboratory of Yasuo Kuniyoshi, performs research in the field of cooperative behaviours, especially regarding active vision and imitation. Humanoid robotics was introduced recently (partly integrated in the Real World Computing Project – RWCP). The group itself is internationally oriented, thus four of the seven members are coming from Australia, Finland, USA, and France. From the research topics discussed, cooperating robots and the imitation aspect will be highlighted briefly.

Based on monocular vision sensors, the robots in the laboratory use optical flow methods and zero disparity filtering to generate behaviours like dynamic collision avoidance (collision avoidance with each other while continuous driving), passing each other, and unblocking the paths of other robots by predicting potential collisions. In this complete multi-robot environment the relation between autonomy and social interaction is investigated [9].

As a related stream of research, the principles of imitation are studied considering the example of pick and place operations, where humans take the part of the teacher [1]. The results are dedicated for a humanoid robot also, which is currently simulated, but is intended to be implemented physically in the very near future.

4. Mechatronics

Mechatronics as a definite bottom-up strategy for robotics research triggers all robotics disciplines by supplying immediate feedback loops as a basic precondition for interaction, or when expressed more generally, by supplying 'bodies' for the 'brains'. Moreover the 'brains' of artificial vehicles are getting more distributed and coupled more closely with the 'body' elements (following biological systems), thus a strict distinction is questionable now.

Mechatronic aspects are considered here by: suggesting a complete frame for modular creatures (the group of *Masahiro Fujita* at Sony), building complex kinematics (laboratory of *Takashi Emura* and the group of *Eiji Nakano*), studying and generating humanoid movements (laboratory of *Hikaru Inooka*), by investigating in control and µ-mechanics (laboratory of *Toshio Fukuda*), and by studying complex dynamics underwater (laboratory of *Tamaki Ura*). The modular earthbound creatures at SONY and the underwater activities from Tamaki Ura will be picked for a short discussion.

4-1. Sony Corporation
Tokyo

Robotics research at SONY (outside the SONY computer science laboratory, discussed individually) is performed in the group of Masahiro Fujita at the D21 laboratory, Tokyo. The driving application is entertainment robotics, where all levels of robotics problems are attacked from scratch, meaning almost any hardware and software is designed at Sony. Moreover it is tried to establish a new standard on the new market of entertainment robots (OPENR) and to support robotics research laboratories.

The presented vehicle is a fully autonomous, 12 DoFs four legged robot with visual and auditive on-board capabilities, and showing complex, entertainment behaviours [4] – a light-weight and in the sense of Rolf Pfeifer [12] well balanced artificial creature. The video camera, as with most other parts of the system, is especially designed for the robot and utilizes a volume of just 4 cm^3.

4-2. Ura Lab. University of Tokyo

Tamaki Ura is one of the pioneers in autonomous underwater vehicles and his laboratory was and is involved in many international underwater activities. Different research directions are followed thereby. Where the emphasis is on long-range autonomous vehicles in the 'R-One' project (together with industrial partners for e.g., sea operations and an encapsulated diesel engine) the 'twin-burger' research platform is employed for intensive vision research, connectionist control strategies and map learning. Most of the 'land-robots' research aspects are investigated, but in a far more demanding, unpredictable and dynamic environment. For an overview of underwater activities in Japan please refer to [16].

5. Remarks & Conclusions
Politics, Motivations, Organizations

Where this report could only stake out the field based on selected examples, the authors hope that this short excursion rose at least some interest in this diverging field of Japanese activities. For a more complete overview please refer to e.g., [20]. In order to sum up the our impressions of the many presented systems and the many discussions and talks, the authors would like to emphasize some outstanding aspects here.

There is an overall tendency to manufacture nearly everything from mechatronics to sensors, chip design, and programming within one environment. This seems to be correlated with the tendency to work on small and µ-robots. They require special components and re-working designs which were successful for larger and more common platforms.

Usually only one or two people, often students or PhD candidates, are designing an experiment and the robot platform most suitable to it. I.e. there are many different and heterogeneous projects going on like a swarm of scouts finding pathways through an unknown jungle. A large and homogeneous project where, for instance, ten or more researchers worked upon, could usually not be found. Seen from the perspective (which is shared strongly by the authors) that there is not only one successful or correct way to come up with a good robot design, this looks very promising. The questions tackled are generally coupled very loosely with an actual application. The authors had the feeling that a kind of humus is generated out of which within the next 5 or 10 years the most successful approaches will be selected and transferred into practice.

The laboratories are often headed by senior scientists who spent some years either in the USA or in Germany often to obtain their Ph.D. and they are very aware of the international scientific community. They are materializing the promise of the Japanese government to repay the international family of nations for what Japan obtained from it in the first place. The authors are appreciating the open-mindedness and willingness to explain what is going on in the laboratories which went far beyond the common kindness of treating a foreign guest. There was never the impression that some information was withheld, of course except the usual confidence required for joint ventures with industries.

The report is focused on local projects and approaches, but it should be at least mentioned that some impressive long term initiatives (like the *Brain Science* research program at RIKEN) are established supporting many of the mentioned ideas by supplying a perspective far beyond the common 'two–or–three–years–application–driven–funding'.

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