50-Year Outlook of Robot Technology
Future Vision and Technical Challenges

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Abstract. Academic roadmap of robot technology 2008 is the result of collaboration by three major robotics research societies in Japan: The Robotics Society of Japan, Japan Society for Artificial Intelligence, and Japan Ergonomics Society, to illustrate the 50-year outlook of robotics world by examining its 50-year history of evolution, and to identify 30 important problems as "robot challenge" to young researchers in this field.

1 Introduction

Academic roadmap of robot technology 2008[2] is the result of collaboration by three major robotics research societies in Japan: The Robotics Society of Japan, Japan Society for Artificial Intelligence, and Japan Ergonomics Society. The activity started from 2006 and the first year report[1] is published in April, 2007 by mainly summarizing the 50-year evolution by examining the history.

As the second year activity, we defined the following three outputs in order to make our activity more productive and effective:

– Robot Future Image - to illustrate the future world with robot and to identify the goal,
– Robot Evolutionary Graph - to illustrate the evolution by merging 50-year history and 50-year outlook,
– Robot Challenges 30 - to identify the important problem which should be solved by young robotics researchers.

The activity has been supported by Ministry of Economy, Trade and Industry (METI) and the result should be reflected in their strategic roadmap of robot technology. The team consists of three working groups: the human integrated system research (hereafter HISR), the information related research (IR), and the advanced engineering research (AER) group: each working group consists of about 12 organizing members led by chief and sub examiner. Each organizing member takes charge of the section of the report and manage the manuscript written by the technical expert in this field. Over 100 experts contributed to the report. The relationship between 3 working groups is shown in figure 1. It shows the relationship between their research category and goal image. There are some overlaps in research category but the trend is that IR group emphasizes the intelligence whereas AER group emphasizes the effect on environment, safety and comfort.

We believe that robot as a research subject should have three major roles as follows:

– Role to Support Human: It is expected that by collaborating with robot, we can solve the problems of aged society with a fewer number of children and environment resource limitations. In this report, we categorized the robot’s supporting functions by worker, fusioning cure, friendship and symbiosis.
– Role to Understand Human: Robot is considered as information-driven machine and we categorized its information-specific future challenge by three kind of intelligence: (1) autonomous system intelligence, (2) social system intelligence, and (3) augmentation of human beings.
– Role to Encourage Human: People are always impressed and excited when they see the motion of robot. Robot is the best teaching material for scientific education. It is expected to be a driving force to attract young researchers in this field.

This is epoch-making project to overview the robot by 100-year scope now: The robot’s history is short compared with automobile’s and its industrial impact is still smaller than automobile industry except industry robots, but we expect this report shows something to lead new direction of robot research and industrial applications. Of course, there are some ethical issues surrounding robot such as military application and privacy, as technology in general has the same issues, but in robot we need to establish a harmony between technology and ethics.

[3] All the images are taken from the original Japanese report[2]
2 Future Image

The figure 2 illustrates what our world will look like in 50 years with robot. Human beings reside in the center of the circle which stands for the earth and also environment. This means that robot technology should be for human, and related with human, and harmonized with environments. Human being is also characterized by 3 systems: (1) physiology, (2) feeling, and (3) psychology. In the lower hemisphere, many kinds of advanced technologies and their applications are shown. There are 5 directions of applications: (1) work support, (2) fusioning, (3) cure, (4) friendship, and (5) symbiosis. The upper hemisphere shows three goal images which robot technology aims at: (1) autonomous system intelligence, (2) social system intelligence, and (3) augmentation of human beings. The arrows between the human and the applications and the goals show the important research subjects. Space in background shows that robot technology enable us to broaden the frontier by eliminating the limitation of our region of existence.

3 Evolution Graph

Figure 3 shows the evolution graph which clarifies the relationship between the items that are discussed in the 3 working groups. The item’s color green, blue and red represents that the items are mainly discussed in IR, AER, and HISR groups, respectively. The upper section shows the evolution of the intelligence of social system and robot. It connects the items such as "autonomous system", "ontology", "sensor network", "distributed collaboration system", "collective intelligence", "recognition of importance", "social intelligence", etc. The middle section shows the evolution of the human support system. It connects the items such as "sensing and recognition", "human monitoring", "special-purpose robot", "in-house service robot", "humanoid", etc. The lower section shows the evolution of the human-machine fusion and augmentation of human beings. It connects the items such as "artificial organ", "BMI", implant device", "multi-scale simulation", "human model", "cyborg", "brain interface", "robotization", etc. At the bottom section, ethical evolution is given from "Declaration of Helsinki" to "robot ethics" and "cyborg ethics".
4 Information Related Research Roadmap

In this section we give a little more detail on the information science/technology aspects of robotics. The IR evolutionary graph focuses not on the linear advances of the individual topics but on the fusion and branching of the flow of evolution. In order to attain these purposes, we predicted what will be realized in 50 years from now, and identified the most important problems to be solved for such realizations.

4.1 Three Goals and Important Problems

The future realizations are summarized into three goal images as follows:

1. Autonomous Systems Intelligence: Systems capable of understanding the meaning and importance of information, self-referencing, and autonomous goal setting.
2. Social Systems Intelligence: With networking of all the systems and sensors prevailing throughout the society, fused with the collective intelligence from humans, the entire system acquires autonomy.
3. Augmentation of Human Being: By connecting to artificial systems via information and physical means in various ways, an existence of human being will be augmented in many directions.

Three most important problems to be solved on the way to these future realizations are identified as follows:

1. Fusion of information, physics, and humans: Since the sectionalism between software-hardware, physics and information theory cause the limitation of the programming, control, and intelligent computation, we need to establish a paradigm to fuse these research. The tight integration of human-machine is necessary to define the criteria which autonomous system should act on.
2. Capability of understanding the meaning and importance of information, as well as evaluating and choosing from them: Quantum computation will enable a real world simulation program to compute all the candidates in a second. However it is meaningless without interpreting of the results. The vast
amount of information on the Internet is only useful when the system understands the meaning and importance.

3. Networking between words, body and physiology: Since the current information system can only manipulate based on the description, it is inflexible to a small change in real world. It is necessary to interact between descriptive and indescribable events. In human-beings, it is the case between the language and physiology/body feeling. Thus we need to understand this interaction and utilize it for the construction principle of information science.

4.2 50-year Future World by Robot Information Technology

Information related future world is predicted by connecting the keywords that we identified as important technical milestones.

"The solar system network" is established to share all the information instantly by "quantum communication" and "tightly-coupled distributed systems", and these information is evaluated by "quantum computation" and the results is also connected to the real world by "ubiquitous network" and "the fusion of physical and information world".

"Self-reconfigurable robot" materializes the simulation results by "seamless simulation" and "adaptation of function and morphology". Also it is used for artificial arm by "hyper personalization" and "cyborg". People enjoy "parallel life," experiencing a real life and virtual lives at the same time by "whole human simulation" and "tele-existence". People "telepathy" each other by "in-body communication" of "inplanting device". These are "augumentation of human beings".

Society integrates the world information from "sensor network" and people knowledge by "symbol grounding" and extracts the meanings by "recognition of the importance". The "social system intelligence" is generated from "collective intelligence" by maintaining the consistency by "homeostatic computing" and it is evolving as if it is "self-organizing" "autonomous function integration".
In order to access to the intelligence, it is not necessary to use a terminal "interface-free society". Ubiquitous robots always give a meaningful services "100% service robot", which understand human in "feeling, motivation, sensibility, and intention" by "fusion of human and information".

The "safe and relief" is guaranteed by "mobile agent". Many types of "Frontier robot" extend the region and feed back the knowledge to establish "robotized world" which "externalize the knowledge".

Humanoid robot has "artificial muscle" and "5 sense device" and it is a life system by "sharing of all device information", "hyper-multi freedom distributed control", "self repair", and "self connection". It also can act flexibly by "adaptive inventing system" and obtains "autonomous system intelligence" by "meta cognition" and "autonomous goal setting".

4.3 Information System Milestone

Information system evolution map is separately drawn and the important milestones which is necessary to realize the goal image: are identified:

- Quantum communication/quantum computation: The technology will cause the revolution of whole range of information processing. It is also a pace-maker for the evolution of other technologies.
- System design for self-organized distributed system: Existing top-down design methodology does not work for the self-organized distributed system.
- Self-referencing/self-evaluation/self-repair and inventing and understanding of goal/intention: In order for robot to make life as a member of society, it is necessary to act voluntarily by understanding human intentions and objectives.
- Cognition development system: In order to get the total autonomous, it is necessary to have a mechanism to develop a cognitive capability via interaction with outside world.
- Whole human multi-scale simulation: In order to optimize the reaction, it is necessary to make a detailed simulation which includes all the levels through molecular dynamics, physiology, cognitive science, and cultural activity.

5 Conclusions

In this paper, we gave an overview of the academic roadmap on robot. The 50-year future image seems to be a dream, but all the image is based on the knowledge of experts in the fields. The evolution is accelerating every year and new technology such as quantum computing will be able to change the world dramatically. Thus we are very optimistic to draw this adventurous future. The intention of this 50-year scale roadmap is not a technology forecasting by a passive observer like weather forecast, but a declaration of the resolution of what direction our research should proceed to realize our future.

References