Industrial Robots

(1) Aims

The Robotics & Mechatronics division covers very large areas. It is difficult to point out the key parameters for looking over and predicting the comprehensive technical development and discuss the future of these technologies. Thus, in this roadmap, we decided to focus on the industrial robots that have been increasing the social and technical importance. (Definition of industrial robots: automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which may be either fixed in place or mobile for use in industrial applications)

(2) Social and technical needs

The social and technical needs of the industrial robots are liberating human beings from so-called 3K work (Kitui=hard, Kitanai=dirty, and Kiken=dangerous work) as workers in the age with a low birth rate and many elderly people, improving the work efficiency, reducing costs, providing highly reliable work (free from human errors), and cooperation with human workers in cell production.

(3) Key parameters

(a) Mean power rate density

The product of the maximum mass that may be carried by a manipulator and the maximum reach of the manipulator are regarded as the maximum load torque applied to the manipulator, and the product of the maximum load torque and maximum acceleration (maximum angular velocity/acceleration time) are divided by the total mass of the manipulator. It is called the mean power rate density. It represents the output performance per unit mass. It also shows macroscopically the cost performance, since the mass of the manipulator has the substitute characteristic for the cost.

The graph shows the mean values of the large, middle, and small vertical multi-joint robots, which are the representative robots used currently. The values have reached the top, though they were increasing constantly until 1995 or so. They kept on increasing mainly because the performance of servomotors and speed reducers were improved owing to the progress in design technology. Progress in magnet performance, insulation technology and high-density winding technologies reduced the sizes and improved the outputs of the servomotors. Small-size and high-rigidity speed reducers were developed and used widely. Since then, the design technology and the control technology for making full use of the mechanical performance progressed, and the values rose a little.

(b) Accuracy

Accuracy is a very important parameter for effective robots. The mechanism accuracy, presence or absence of external sensors, and compensation methods are the elements of the accuracy. The positional repetitive accuracy has been improved: from 1 mm to 0.5 mm ～ 0.3 mm in the case of large robots, and from 0.1 mm to 0.05 mm in the case of small robots. Absolute accuracy is not guaranteed normally, but that of robots with special functions is improved from 5 mm to 2 mm. The factors of accuracy improvement are improvement of the actuators, speed reducers and encoders, progress of the calibration and control methods, and application of external sensors.

(c) Intelligence level

A robot’s history is also the history of the improvement in an intelligence level of a robot, not limited to the industrial robots. The graph shows this history from the viewpoint of autonomy improvement. Objects of intelligence provision are roughly classified into teaching and work. The former means how easily and efficiently preparation for work may be made. The latter means how accurately and efficiently work may be carried out. It is expected that progress of intelligence will expand the application fields of industrial robots.

Teaching takes a long time and is an important element directly related to production costs. At the beginning, positions and postures were specified delicately online along the moving lines in robot teaching. Then, interpolation computation reduced the number of teaching points, and offline teaching in linkage with CAD systems is the current tendency. However, the system accuracy and the capability of trace generation software are not perfect at present and online correction is necessary. As for intelligent work, correction functions with external sensors are added to simple teach and playback method used before, and misalignment and deformation of work may be corrected to some extent. Thus, autonomy in position control is improved. However, insufficient performance of external sensors restricts robot performance. In assembly requiring force control, development of the control theories and sensors is not enough. This also applies to the fields where robots should be applied to inspection work.

(4) Future directions for determining key mechanisms and parameters

(a) Mean power rate density

Transition of drift cannot achieve great improvement. The solid line shows the expected transition. To increase the value at the rate shown in the broken line, some breakthrough is necessary. Much effort is placed on weight reduction (rigidity improvement) accelerated by progress of the material technology and further improvement of servomotors and drivers. In some robot designs, the rated specifications are changed into instantaneous performance specifications. This concept may be promising breakthrough.

(b) Accuracy

Repetitive positional accuracy has been used to evaluate the accuracy of industrial robots. It is expected that demands for absolute accuracy will increase in the future. However, absolute accuracy cannot overcome repetitive positional accuracy. In robots requiring absolute accuracy, absolute accuracy may be improved close to repetitive positional accuracy. Even though the robot may have

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absolute accuracy, the system cannot demonstrate its full performance if workpieces have insufficient accuracy. After all, the method of controlling the relative positions with workpieces using additional sensors will be the main stream of high-precision processing. If the robot-to-workpiece relative position control advances, actual work efficiency will be remarkably improved.

(c) Intelligence level

Demands for offline teaching will increase in the future. It is necessary to ensure absolute accuracy and develop work planning skills requiring no on-site corrections. We expect that such technologies will be actualized if the environment structuralization technology and related technologies are combined. Much expectation is placed on progress in interface technology for efficient information exchange between robots and human beings. Higher safety is required for cooperation with human beings and development of necessary technology is important. For intelligent work, it is expected to apply new control theory capable of enabling higher-speed and higher-precision work. Advanced external sensors and high-speed information processing will significantly contribute to the improvement of intelligence level.

(5) Contribution to society

- Robot performance will be improved. Robots will be applied to the fields where no robots have been used, and the market of the industrial robots will expand.
- As the robot technologies progress, work that can only be carried out by human beings will be reduced and automatic work done by robots and man-robot
- cooperative work will increase. As a result, the Japanese manufacturing industries will maintain their international competitive forces even in the age with a low birth rate and many elderly people.
- Robot teaching operations will become simpler, and cost performance will improve further. As a result, robots are used more widely in not only large-scale enterprises but also middle- and small-scale enterprises, contributing to solution of manpower shortage in middle- and small-scale enterprises.
- Structuralization of environments where robots may work easily may be easier in factories than in homes and general society environments. In cooperation with development of intelligent robots, such environment structuralization will expand the areas to which industrial robots may be applied.
- As the industrial robot capability is improved, the technical results will have influences upon non-manufacturing fields and contribute to development of robots for various non-industrial uses.
- In the age with a low birth rate, people liberated from the manufacturing industry may be engaged in work in various fields, manpower will be re-distributed, and the active power of the society will be maintained.

Social & Technical Needs

1980～1990	・Promotion of automatization in factories ・Liberation from 3K work ・Stabilization of product quality
1990～2000	・Improvement of production efficiency (welding, handling, inspection, painting, assembly, mounting, etc.) ・Attaching much importance to product quality ・Needs for improving repetitive positional accuracy
2000～2010	・Countermeasures against product diversification ・Means of avoiding deindustrialization ・Cell manufacturing (Multi-function manufacturing) ・Wider applicable fields (than mentioned above) ・Fields requiring absolute accuracy
2010～2020	・Countermeasures against age with low birth rate and many elderly people(Robotization of skilled work) ・Support to work conducted by human beings ・Wider applicable fields (than mentioned above) ・Increase of sensor utilization
2020～2030	・Countermeasures against decrease of working people ・Combination with life supporting robots ・Industries out of factories ・Simple operation by ensuring necessary accuracy

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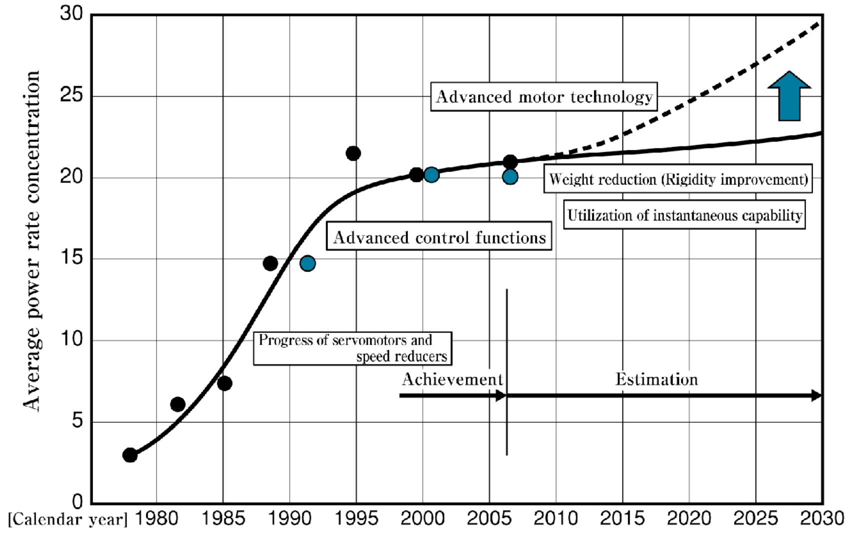

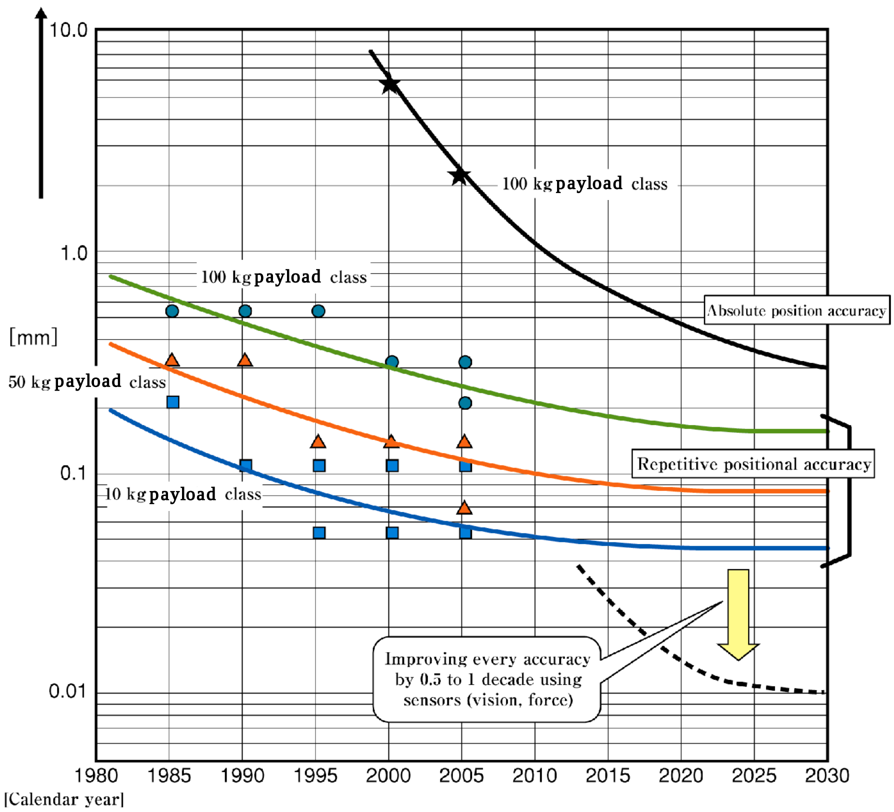

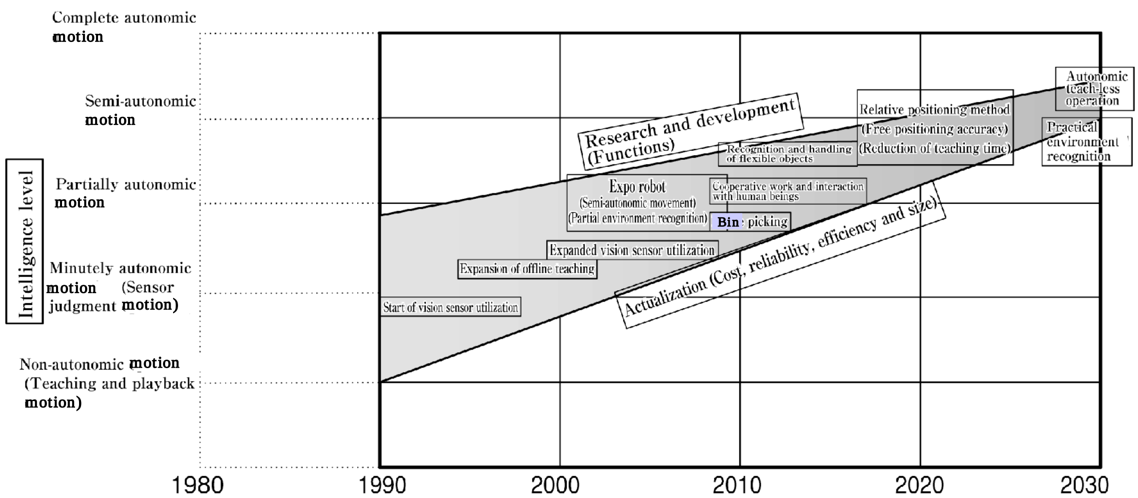

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Technical Breakthrough

1980～1990	・From hydraulic type into electronic type ・Multi-function robots (interpolation computation function, etc.) due to progress of micro-processors
1990～2000	・Size reduction and power improvement of servomotors and size reduction and rigidity improvement of speed reducers ・Multi-function HMI
2000～2010	・Accuracy improvement due to progress of robot-workpiece relative positioning control
2010～2020	・Weight reduction (high rigidity) due to progress of material technology and improvement of mean power rate density due to further progress of servomotors and drivers
2020～2030	・Improved intelligence due to progress of offline teaching and interface technology for efficient information exchange between robots and human beings

Changes in Society and Markets

1980～1990	・Society was ready to accept robots. ・Industrial robots were popularized in car industry and had wide applications.
1990～2000	・Windows PC was propagated. ・Communication (between robots and other equipment)
2000～2010	・3D CAD systems were widely used. ・Safety standard was revised. (Cooperative work with menhuman beings were enabled.) ・Cell manufacturing enabled production of many kinds of products. ・Estimated sales of robots in Japanese market: 0.5 trillion yen (2005)
2010～2020	・Estimated sales of robots in Japanese market: 1.8 trillion yen (2010) ・Market of highly intelligent robots expands. ・Interactive robots (Simplified operation) ・Brain mechanism discriminating specific voices among noises will be applied to communication and 50X (100 megabits/sec.) high-speed communication will be enabled. ・Damage-less surgical technologies using micro-machines and robots will share lar
2020～2030	・Robots are widely used in small factories. ・Logical deduction mechanism in brains is made clear. ・Estimated sales of robots in Japanese market: 6.2 trillion yen (2025)

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