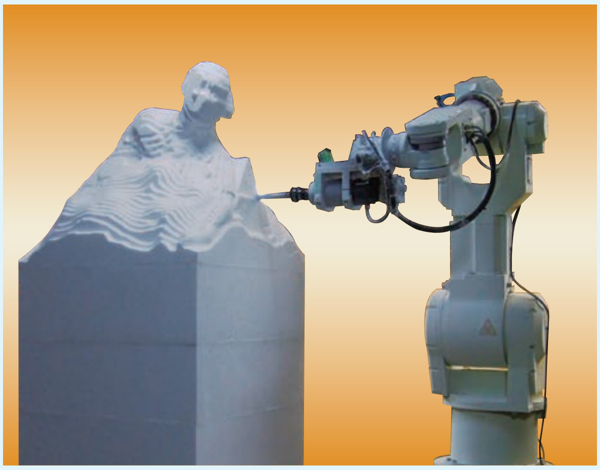
Precision-machining robot system



The enhanced precision of industrial robots and progress in their peripheral technologies have allowed robots to enter the field of machining. The wide operation range and affordability of the system offer the prospect of replacing NC machine tools in the prototype modeling field. This paper provides a commentary on milling robot systems for precision machine and presents examples of precision processing with robots.

Preface

Thanks to their versatile configurations, affordable price, and advanced ability for faithful repetition of operation instructions, industrial robots have evolved through application for automation of welding, painting, and other operations centering on the automobile industry. Furthermore, an increasing number of users have in recent years been making use of offline teaching with computers to shorten the time required for production planning proposals and line startup. To better meet these needs, industrial robots have acquired greater absolute accuracy for precise positioning into the specified spatial position as well as repeatability for faithfully repeating operations.

As robots have increased in precision through technological advances, demands for robots as substitutes for NC machine tools have also increased. But since robots generally have a cantilevered structure resulting in low rigidity, they are not suited for micron-order ultra-precision machining. Nevertheless, because robots offer a wide operations range and reasonable price levels, their application is expected in areas where micron-order precision is not necessary and the use of high-priced large machine tools would constitute a waste of resources. In addition, even in laser machining and other machining processes requiring sub-millimeter precision, where robot applications have previously been difficult due to insufficient precision, the possibility is increasing for application of low-priced industrial robots.

1 Application of robots to machining processes

In the process of developing new automobile models, as many as 40 to 80 seat prototypes processed out of urethane or Styrofoam rolls, etc., are produced for each model by the completion of the final design. While NC machine tools have been used in the past for this kind of prototype machining, the use of high-priced NC machine tools constitutes an overperformance in terms of precision. Moreover, sublimation patterns of prototype molds for industrial machinery, camera or printer models, and wood machining require the same level of precision as the seat molds or less.

If industrial robots are used in these fields, we can expect the following benefits.

① Cost reductions due to use of low-price robots.
② Achievement of wide-ranging 5-axis machining, including wraparound operations.
③ Combined use of traveling equipment and turntables for selecting flexible system configurations in accordance with workpiece size.

However, achieving substitution of NC machine tools will require an industrial robot with the necessary precision, and use of 3D CAD/CAM data to perform machining while using simulations to check for robot interference, etc.

In fact, there are areas where robot substitution is possible, and areas where only NC machine tools can be applied. These areas are shown together with their relationship to machining precision and market scale in Fig. 1. The machining precision required depends on the target workpiece. Therefore, we created a milling robot for practical application by increasing the robot precision and realizing a system demanded by the market.

2 Technology for achieving precision machining

To use industrial robots, whose development has mainly centered on the teaching playback function due to repetitive operations, as substitutes for NC machine tools, the following issues need to be addressed.

① Improvement of absolute accuracy through correction of machine difference and deflection
② Software for conversion of multipoint (hundreds of thousands of points) machining data into robot programs
③ Suppression of micro-vibrations in robots that occur in resonance with periodic variations (ripples) generated in reducers
④ Precision tool measurement with no machining position offset due to changes in the end mill posture

(1) Improvement of absolute accuracy

While industrial robots have a precision of 0.1 mm for repeatability (precision in the reproduction of teaching positions), their absolute accuracy (precision in moving to positions specified with coordinate values) is not as high. This is due to robot machining and assembly errors, zero-point errors of the joint angle sensors, or arm deflection. To ensure accurate positioning, we developed a technology that takes these error factors into consideration to correct the command position and hold the robot's average absolute accuracy to 0.5 mm or less. We also perform measurements before shipment to identify the robot part dimensions, the joint angle sensor zero point, and the rigidity of each part, and input the data to the robot controller, to achieve high-precision position correction.

(2) Conversion from G-code to robot program

In general, output from CAD/CAM to NC machine tools is performed in the industry standard format known as G-code. We have developed software for automatically generating robot programs from this G-code machining data. Since the user can continue using the G-code machining data generated for NC machine tools, the milling

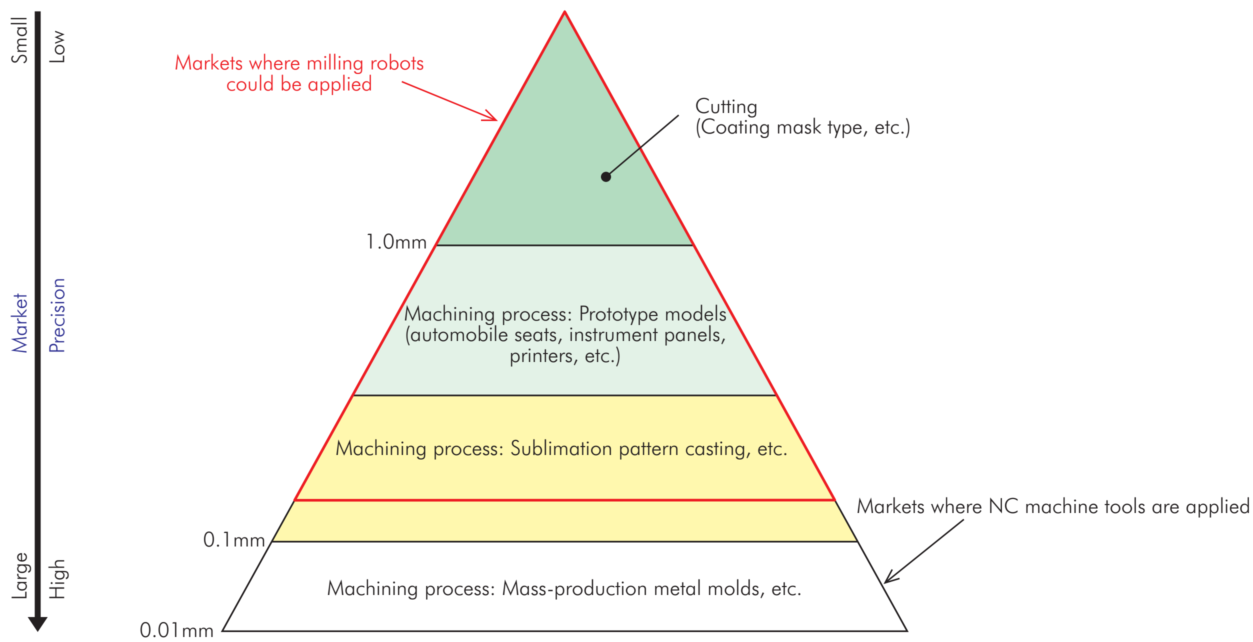


Fig. 1 Machining accuracy and market size

robot can be used without any special work on the part of the user. Furthermore, a simulation function of the KCONG for MILLING software, which automatically generates the robot program, lets the user check beforehand whether the operations range will be sufficient, or whether there will be interference. We use a DNC (Direct Numerical Control) server to send the robot program to the robot. Processing data flow for the milling robot is shown in Fig. 2.

(3) Suppression of micro-vibrations

Industrial robots use reducers with low backlash to improve positioning accuracy. Since these reducers achieve a compact size with high load in addition to the low backlash, they have a structural disadvantage of easily generating periodic torque variations or angular transmission errors. While this reducer ripple itself is small and normally does not cause a problem, when the ripple vibration matches the robot's own natural frequencies, it can generate micro-vibrations with amplitudes of around 0.2 mm, which can affect the machining process. When this micro-vibration is generated during a machining process, it can cause wavy microscopic irregularities in the workpiece being machined.

Depending on the posture, industrial robots change their inertia and alter their natural frequencies. In addition, even when tools are operated at a constant speed, the rotation speed of each articulated joint changes, making it difficult to avoid resonances caused by reducer ripples by manipulating the machining speed or natural frequencies.

Therefore, we use a method of adding signals to the motor torque command for extinguishing the ripples, which greatly reduces these micro-vibrations. With this method, we successfully reduced vibrations during workpiece machining to a level where scratches are no longer visibly discernible.

(4) High-precision tool measurement

In five-axis machining, the direction in which the end mill accesses the workpiece can change. As a result, if robot tool registration is not correctly performed, changes in the end mill posture can offset the machining point and create uneven surfaces in the workpiece after machining. While the industrial robot is equipped with the standard tool measurement method, it is not sufficient for performing five-axis precision machining.

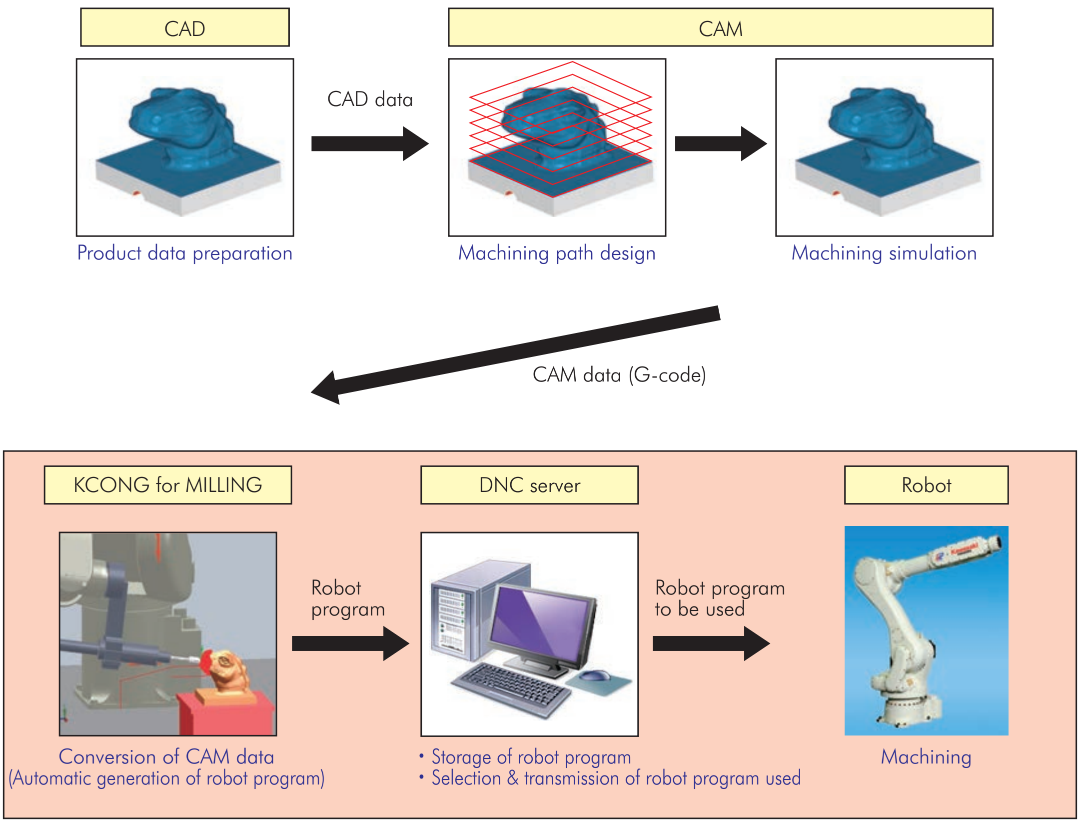


Fig. 2 Flow of machining data

Therefore, we developed a tool measurement method using a reference tool with a sphere attached to the end and a projection-type position sensor. An example of an actual tool measurement process is shown in Fig. 3. We operate the robot using sensor information so that the sphere's center position does not change, and then we read the robot's joint angle at that time to measure the tool position. Then, we switch to a reference tool with a different length and perform the same operation to measure the tool rotation axis.

Combining this tool measurement method with the robot's high-precision position correction technology, we achieved five-axis machining without generating uneven surfaces.

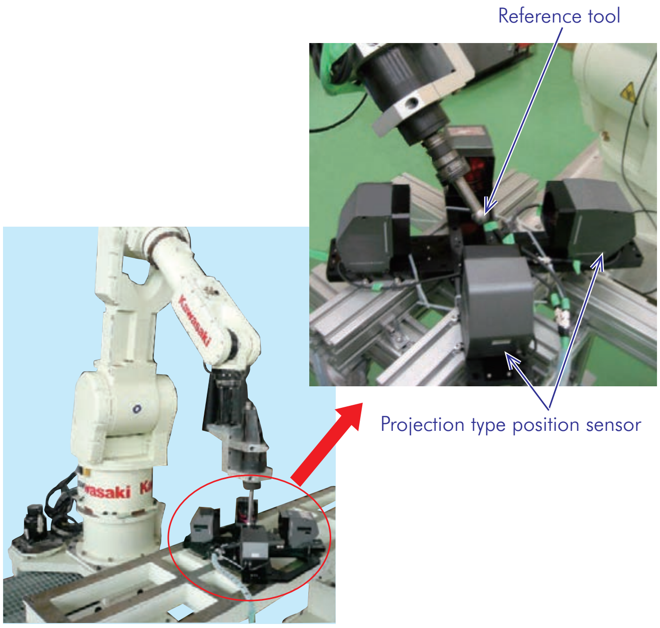


Fig. 3 Precision tool measurement

3 System configuration example

An example of a milling robot system configuration is shown in Fig. 4. The installation space is smaller than an ordinary NC machine tool, and layout changes are easier to make. Furthermore, by using a spindle replacement device to replace the spindle (machining axis) used for machining with a robot hand or other tools, the system can conduct such operations as loading or unloading of machined workpieces, or measurement before or after machining.

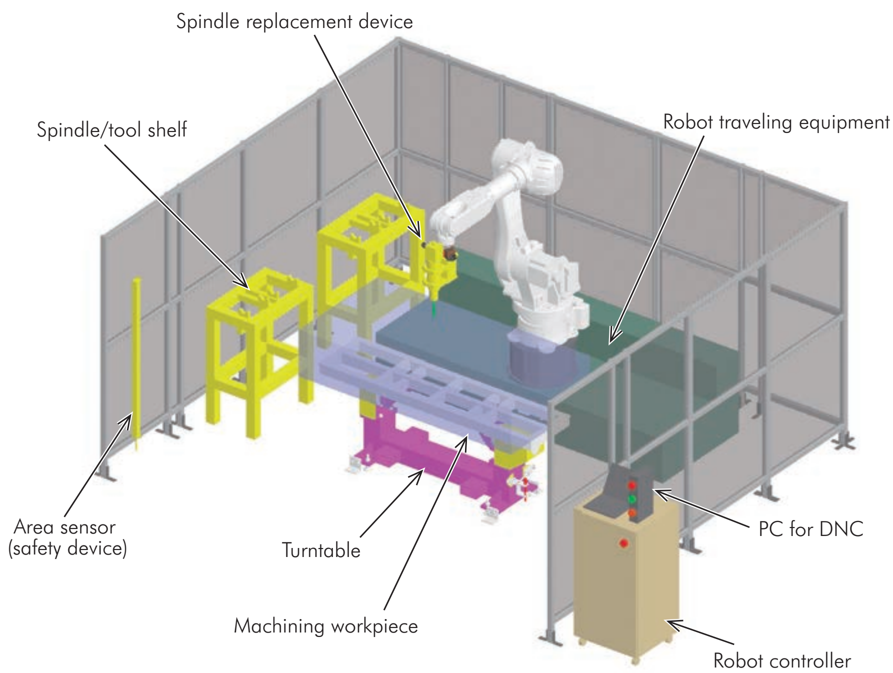


Fig. 4 Example of milling robot system

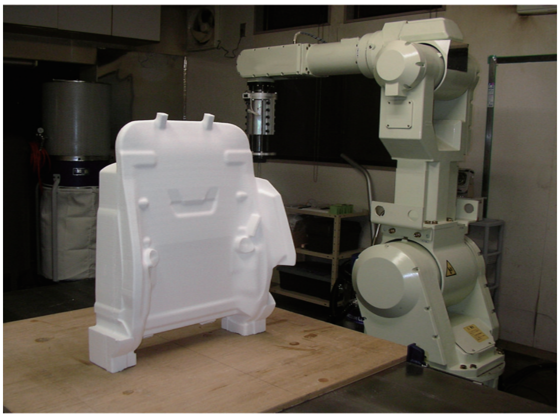


Fig. 5 Automobile seat prototyping

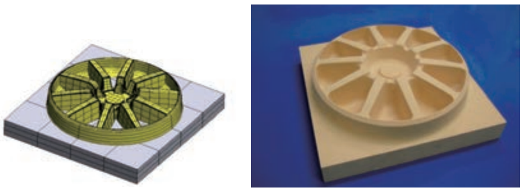
4 Application example

A machining example for an automobile prototype seat model is shown in Fig. 5. One robot can machine a workpiece the size of a seat for one person.

Other machining samples are shown in Fig. 6. While these sample parts previously required the use of NC machine tools, with milling robot machining we achieved space savings and lower costs.

This system was adopted for Nike Japan's 2010 FIFA World Cup campaign that was run in support of the athletes. As shown in Fig. 7, a robot carved messages collected from supporters into a life-size statue of an athlete, adding to the excitement of the World Cup.

(a) Automobile modeling (Styrofoam)



(b) Wheel (chemical wood)

Fig. 6 Sample works

5 Deployment to other processes

With high-precision machining now possible using industrial robots, deployment to various applications can now be expected. An example of impeller laser welding is shown in Fig. 8[1)]. In addition, since free-form surface machining can be performed based on G-code, applications to curved surface finishing can also be expected.

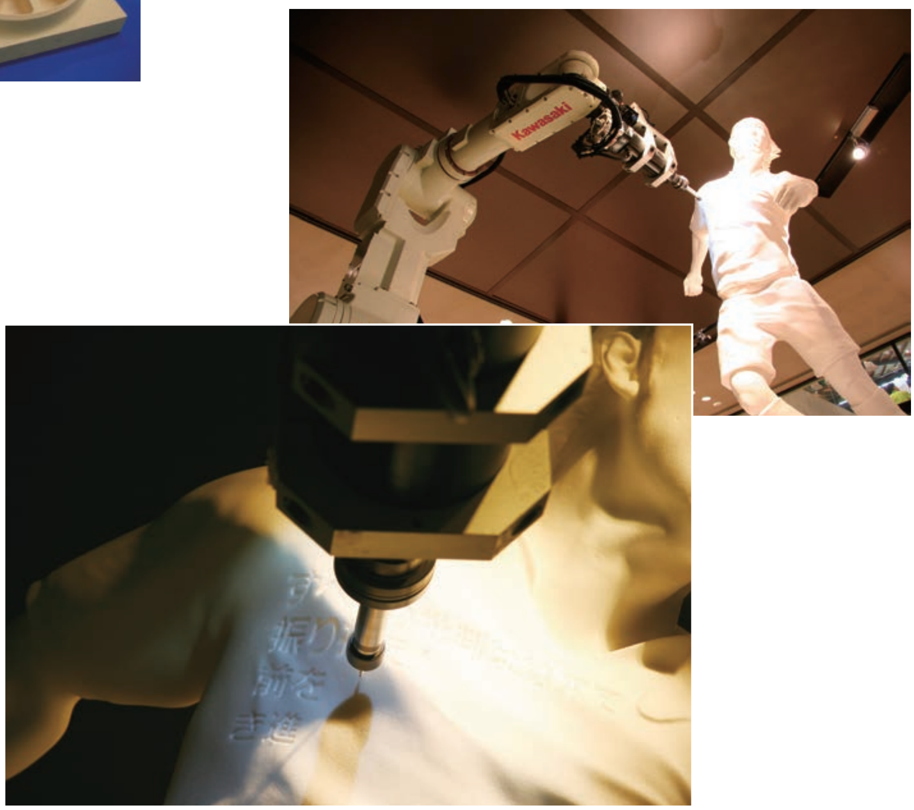


Fig. 7 Nike Japan "2010 FIFA World Cup" campaign

Fig. 8 Application for laser welding

Concluding remarks

Machining processes, an area where industrial robots have not been used in the past, are now open to robot applications with the realization of advanced precision and G-code machining. Just as robots have come to be widely used in the automobile industry for welding and painting, we can now expect to see the use of affordable, versatile industrial robots spread widely in such fields as prototype model machining.

Reference

1) Maeda, Y., Kobayashi, Y., Kuwano, T., Tsukamoto, T., Iwasa, M.: "6.5kW High Power Direct Diode Laser Applications in Heavy Industries," ICALEO2008 Congress Proceedings (2008)

Jun Fujimori
Control System Department,
System Technology Development Center,
Corporate Technology Division

Ryota Ienaka
Control System Department,
System Technology Development Center,
Corporate Technology Division

Yuhei Horiuchi
Control System Department,
System Technology Development Center,
Corporate Technology Division

Doctor of Engineering
Tetsuya Kubota
Control System Department,
System Technology Development Center,
Corporate Technology Division

Noboru Takagi
FA System Department,
FA and Clean Group,
Robot Division,
Precision Machinery Company

Kazuyuki Yama
FA System Department,
FA and Clean Group,
Robot Division,
Precision Machinery Company

Akihumi Wakisaka
FA System Department,
FA and Clean Group,
Robot Division,
Precision Machinery Company

Junichi Kawabata
IT System Department,
System Development Division,
Kawasaki Technology Co., Ltd.