FANUC NEWS 2021-Ⅱ

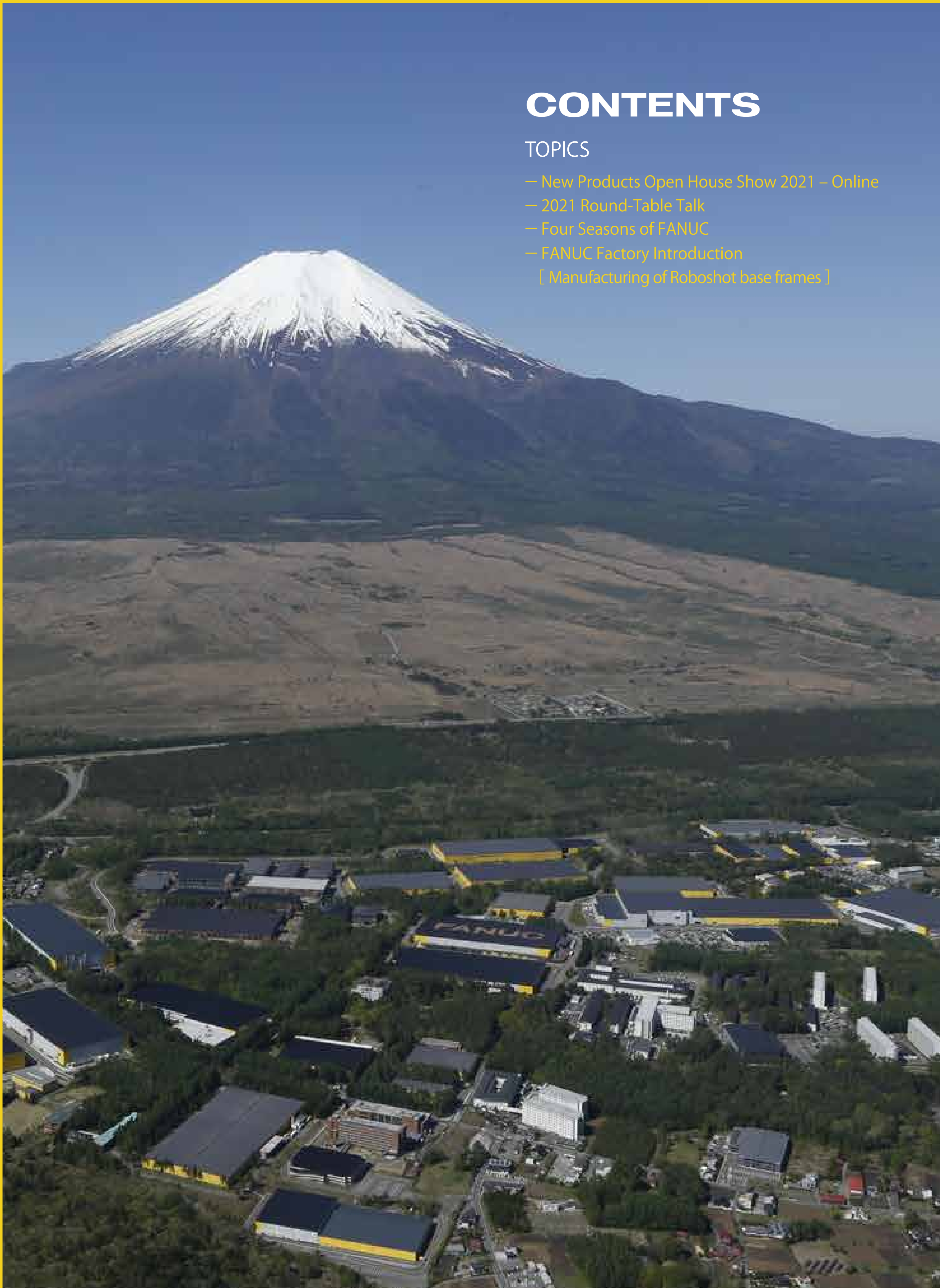

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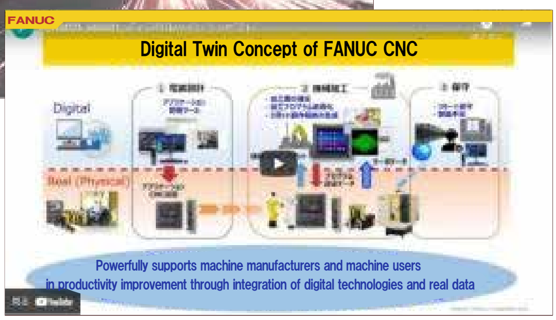
Photo taken May 2021

New Products Open House Show 2021 – Online

The New Products Open House Show was held online for 12 days from June 14 (Monday) to June 25 (Friday) in 2021. This was the first time that the Open House was held online. Many customers in remote locations or overseas who had difficulties in visiting "real" Open Houses were able to participate, resulting in a total of 9,856 visitors during the event.
Like the usual real Open House, the highlights of the exhibits were explained at seminars, and visitors accessed the FA, Robot, Robomachine, IoT, Service, and ACADEMY areas to see the contents that interested them.
Comments were received from visitors expressing appreciation of the advantages of holding the Open House online such as, "It was hard to get near exhibits and hear explanations as there were so many people in real exhibitions, but explanations could be heard clearly without distraction in this virtual Open House."

In the FA area, a wide range of new products and technologies were introduced, including improved functions related to CNCs, servos, and lasers, use of digital technologies, and automation technologies that use robots. Many visitors showed interest in the Digital Twin concept, FANUC *i*PC, and CNC-QSSR, among others.



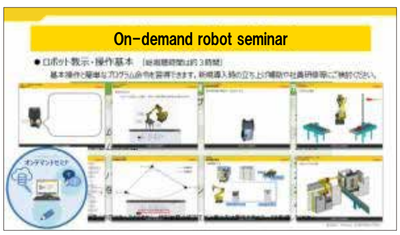
In the Robot area, the functions and application examples of the CRX as a collaborative robot that can easily be used by even first-time users, and new products including a remote laser-welding robot, a SCARA robot with a payload of 20 kg, a high-speed press robot, and a 3D vision sensor for measuring short distances were introduced.
The CRX drew much attention and many visitors were interested in the arc welding package.

In the **Robomachine** area, new products were displayed, including the Robodrill α-D*i*B Plus series, the Roboshot α-S*i*B series, and the Robocut α-C*i*C series as well as the new function of the Robonano called "Smart M-Form," among others. Also, a 360° video circling a Robomachine was shown, which could only be possible in a virtual exhibition. Viewers could choose the direction to see the Robomachine from any point around the machine.

In the **IoT** area, the latest functions of FIELD system, and implementation examples in Japan and overseas were on display, in addition to new functions of MT-LINK*i* and proposals for using FabriQR Contact.

In the **Service** area, service systems in Japan and overseas, details of service activities, improvements in customers' operating rates, and FANUC's lifetime maintenance policy were introduced.

In the **ACADEMY** area, the new approaches to training consisting of live seminars and on-demand seminars, which are additions to conventional ACADEMY training courses, as well as the contents of technical training on FA, Robots, Robomachines and IoT were explained.



2021 Round-Table Talk

Professors and researchers who provide FANUC with continuous support were invited to the online New Products Open House Show held from June 14. Afterwards, a round-table talk was held online on June 18.

● Attendees

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Toshiro Higuchi, Professor Emeritus, The University of Tokyo

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Keiichi Shirase, Professor, Kobe University
Hideki Aoyama, Professor, Keio University
Shigetaka Takagi, Professor, Tokyo Institute of Technology
Yoichi Hori, Professor, Tokyo University of Science
Atsushi Matsubara, Professor, Kyoto University
Manabu Tanaka, Professor, Osaka University
Hiroyuki Sasahara, Professor, Tokyo University of Agriculture and Technology
Hidenori Shinno, President, Polytechnic University

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Hajime Asama, Professor, The University of Tokyo
Shigeki Sugano, Professor, Waseda University
Ichiro Sakuma, Professor, The University of Tokyo
Masatoshi Ishikawa, Project Professor, The University of Tokyo

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Takashi Matsumura, Professor, Tokyo Denki University
Masanori Kunieda, Professor, The University of Tokyo
Eiji Shamoto, Professor, Nagoya University
Hitoshi Omori, Senior Researcher, RIKEN
Tsunemoto Kuriyagawa, Professor, Tohoku University

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Tojiro Aoyama, Professor, Keio University

(Listed in order of comments)

FANUC CORPORATION

Representative Directors

Yoshiharu Inaba, Representative Director, Chairman
Kenji Yamaguchi, Representative Director, President and CEO (Moderator)

FA

Hiroshi Noda, General Manager, FA Business Division
Yoshiki Hashimoto, General Manager, CNC Hardware Research & Development Division
Yasusuke Iwashita, General Manager, CNC Software Research & Development Division
Masamoto Fukuda, General Manager, Servo Research & Development Division
Yuji Nishikawa, General Manager, Laser Research & Development Division

ROBOT

Kiyonori Inaba, General Manager, Robot Business Division
Kenichiro Abe, General Manager, Robot Mechanical Research & Development Division
Seigo Kato, General Manager, Robot Software Research & Development Division

ROBOMACHINE

Hiroyuki Uchida, General Manager, Robomachine Business Division
Zheng Tong, General Manager, Robodrill Research & Development Division
Satoshi Takatsugi, General Manager, Roboshot Research & Development Division
Akihiko Fujimoto, General Manager, Robocut Research & Development Division
Youngpyo Hong, General Manager, Robonano Research & Development Division

Administrative Staff

Shunsuke Matsubara, General Manager, Research & Development Promotion/Support Division
Masako Sudo, Assistant General Manager, Research & Development Promotion/Support Division

(Titles are as of June 18, 2021)

President Yamaguchi: I am really grateful that many professors gathered together today despite their busy schedules. I am Kenji Yamaguchi, President of FANUC. This year, we decided to have an Open House and a round-table talk in online form to put safety and health first during the COVID-19 pandemic, even though we usually get together around the time of the real Open House to have a face-to-face round-table talk. We had no choice but to cancel the Open House and round-table talk scheduled in April 2020 due to the rapid spread of COVID-19. This Open House is being held for the first time in about two years since April 2019, although in virtual form. I believe that the contents are rich in terms of technology, though I do not intend to place pressure on our employees. We also have made efforts on how to effectively show our products in an online exhibition through trial and error for the past year. However, the professors here are much more familiar with online events than we are. We would appreciate receiving your straightforward opinions and advice. Let us make today's round-table talk a success.

Yamaguchi

General Assessment of the New Products Open House Show

President Yamaguchi: First, we would like to ask Professor Higuchi to comment on the online Open House as a whole.

Professor Higuchi: Because new products for the past two years are being presented in this Open House, I have been looking forward to seeing the results, even if not in person. First, as a whole, each exhibit and explanation was brief and well organized in an easy-to-understand way despite the restrictions of an online exhibition. I could not see even half of all the exhibits in two or three hours at previous Open Houses, but due to this year's Open House being online, I was able to visit during my free time and saw almost everything.


Professor Higuchi

As a result, I noticed many details I had not known about existing products. I am glad I was able to see the entire Open House. It was a wonderful learning experience.
Because the Open House website first showed the contents of exhibits, I began with individual exhibits. Then, I accessed technical seminars and listened to the explanations of each business unit. In these technical seminars, the FA, Robot, and Robomachine business units presented an overview, the goals, and highlights of their exhibits. It would be better if watching seminars was recommended before seeing individual exhibits.
I felt that this year's keyword for general product development was "ease of use." In the FA area, many of FANUC's efforts related to Digital Twin were presented under the title of "Evolution of Things and Innovation in Ideas."
However, I personally do not like this buzzword, "Digital Twin." Such new terms are often created to give an impression of a brand new concept, but usually just end up confusing people. This term could disappear in four or five years because it is actually a typical concept. The basic concept is nothing new, but it stands out because vast volumes of data can now be processed at high speed at a relatively low price as a result of the evolution of computer and digital technologies.
So, as a matter of course, FANUC has been working on Digital Twin for a long time. Although products have not yet attained the ideal forms expected in the future, FANUC has launched many different new products based on the concept of the real world and a simulated world.
Now that interaction between the world of a simulated model and the real world is almost instantaneous, it is actually becoming increasingly important that machines work reliably and that machining phenomena are properly understood.
It was mentioned in the FA seminar that FANUC will focus on real technologies, and I believe that this is the right direction. In addition, the development of sensors is crucial if there is going to be frequent interaction between the real world and the world generated by a computer. FANUC develops 3D vision sensors and touch sensors for on-machine measurement for ultra-precision machining, and some of them were exhibited in the Open House. My hope is that FANUC will develop such sensors more aggressively.
Next, let me talk about robots. I found them to be the most interesting at this Open House. It is probably because robots are more suitable to be presented online. In particular, it was evident that the collaborative robot is widely used and its usage is quite familiar. The main feature of the FANUC collaborative robot is the highly sensitive force sensor built into the robot to measure the force when it comes in contact with people. At the exhibit, this sensor was used to measure the force when a robot assembled a workpiece. This is an interesting idea.
As for Robomachines, it was clear that FANUC also focuses on ease of use in addition to performance enhancements. Roboshot received the Okochi Memorial Special Production Award last year for the development of an all-electric injection molding machine for producing ultra-precision small compact plastic parts, but it was not presented at the Open House. The Special Production Award is the pinnacle of the Okochi Memorial Award, indicating that the contribution of the Roboshot to precision parts production is highly regarded.
Several years ago, I pointed out that FANUC conducted many different projects but the projects were not closely coordinated

with one another. Seeing this year's Open House, I felt that technologies have steadily been integrated among the three business divisions.
I presume that the COVID-19 pandemic will end next year so that you can have a real Open House. I prefer to see actual products, after all. This online Open House must have given you an opportunity to reassess a real Open House and see the advantages and room for improvement of a real exhibition. I hope that you will have a better Open House next year by combining the strengths of an Open House in real and online form. That is all from me.

President: Professor Higuchi, thank you for your comprehensive comment on the overview of the Open House. I will take what you said into consideration.

FA

President Yamaguchi: Now, let's focus on FA in the first part. First, we would like to hear from Professor Shirase.

Professor Shirase: I am Shirase from Kobe University. Thank you for inviting me to this round-table talk today. I usually speak later in this round-table talk and therefore have a lot of time to think while listening to other professors. Today I am the second speaker after Professor Higuchi, so I am really nervous because I did not have much time to think.

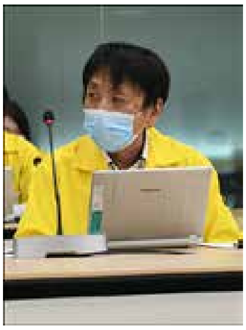

Professor Shirase

As Professor Higuchi has said that he would have rather watched the seminars before seeing the introduction of individual exhibits, I would like to note that I did watch the seminars first. I attended the seminars and listened to the introduction of individual exhibits, and my impression was that the presentations and documents were in line with the common theme of FA, which is the "Evolution of Things and Innovation in Ideas."
There were three seminars about FA, Robots, and Robomachines. I was a bit disappointed to see that there were no seminars on IoT or FIELD system. My guess is that the seminar about FIELD system was not available because the business divisions organized the seminars. However, when you try to change production sites through digital transformation and achieve "Evolution of Things and Innovation in Ideas," linkage with a host system, the means to make full use of a network, and information security are critical. So, it would have been better if you had a seminar on FIELD system.
Because the Open House was held online this year, I spent more time than usual watching the introduction videos of individual exhibits. Holding an event online has both its advantages and disadvantages. Viewers can watch the Open House any time and as many times as they wish. This means that viewers receive all the information that FANUC wants to convey. This is an advantage. A disadvantage of an online Open House is that you cannot ask questions on the spot. I have the same opinion as Professor Higuchi and also hope that you will hold a real Open House next year.
What particularly impressed me is the dramatic evolution of CNC as a result of performance improvements in CPUs. A case-in-point is the Digital Twin that Professor Higuchi mentioned. Faster CPUs enable what was impossible only a little while ago. For example, I felt that the Fine Surface Technology and the Fast Cycle Time Technology have advanced to the next level or maybe even higher. I got the impression that FANUC has considered several different specific means of supporting the design, machining, and maintenance of machine tools from the viewpoint of user support.
I was interested in the optimization of NC programs because I have been studying how to make machine tools intelligent and autonomous for a long time. In the past, machine tools were expected to operate exactly according to an NC program. However, even when doing so, we have come to understand that machining results do not match CAD data. To optimize the NC program, the CNC modifies the NC program using CAD data so that the machining result comes even closer to the CAD data. Although this is very effective, I believe that, in the ideal sense, the machine tool should operate to exactly match the CAD data, as I have recommended for some time.
Because it is taken for granted that the machine tool operates according to the NC program, I suspect that FANUC used this measure rather reluctantly, as the company has to follow the trends of the times. Still, I hope that FANUC's CNCs will introduce a new world of machining, rather than dismissing the conventional way of operating a machine tool according to an NC program. For example, using CAD data to operate machine tools to achieve an incredible machined surface, or to complete machining in a very short time.
In addition, I was impressed with the high level of sophistication of CNC GUIDE and Surface Estimation. CNC GUIDE is a function that accurately simulates the machining time as well as the movement and position of a tool, considering the acceleration/deceleration of the drive axis. The Surface Estimation function obtains the tool position information from an actual machine without conducting machining, and estimates the machined surface in very fine detail. What is a bit disappointing is that the machine tool must be dry run. A dry run enables tool position information to be gathered in order to provide a precise simulation of the movement of the machine. I hope there will be further progress, with which accurate estimation of tool position information is possible even without a dry run. Although, CNC GUIDE and Surface Estimation are very conve-

nient and effective tools, they are currently only available with the CNC in the machine. It would be great from the user's standpoint if exact simulation could be performed on a PC outside the machine. As a compromise, it would be beneficial if simulation were possible on FANUC's IPCs.
As for ease of use, support for NC programming has become very graphical and intuitive. Operators can now create NC programs even without knowledge of G code or M code. Although these codes have a long history, young people are not familiar with them and do not seem to be interested in what is going on behind the scenes, as long as they can create NC programs as if they were playing a video game. So I hope that you will make great advancements in such user interfaces.
Another thing that surprised me was high dynamic turning. This function supports a new machining technology in which the linear and rotary axes are controlled while changing the angle of the turning tool rather than by simply moving the turning tool. I think this is similar to the machining technology that makes full use of tools with new shapes, such as the recent barrel tools for CAM. If this function is implemented in a CNC, CAM will no longer be necessary. While it might be quite difficult to eliminate CAM from FANUC's perspective, I hope that this will lead to a technology that enables incredible machining with CAD data without having to use CAM, which I mentioned before.
As a last comment, the introduction of individual themes shows that IoT and FIELD system have significantly advanced. Many different cases were presented. As the evolution of technologies related to machine tools and CNC, such as edge and fog, now stand out, I hope that FIELD system will be leveraged to achieve "Evolution of Things and Innovation in Ideas" that are linked to supply chains and scheduling on the cloud. Please make full use of FIELD system to develop the world of new manufacturing that FANUC envisions.
Thank you for inviting me today.

President Yamaguchi: Thank you, Professor Shirase. General Manager Noda, do you have anything to add?

Noda: Thank you, Professor Shirase. You mentioned a wide range of topics so I will address some of the main points. We selected Digital Twin as a theme for FA at this Open House and focused on the "Ideas" aspect of "Things and Ideas." Our thinking is that a lot of information in the CNC is processed in the digital world and returned to the real world. In other words, a virtual machine is built in the digital world and its precision is improved by exchanging information with the actual machine in the real world. As a result, machining that is similar to actual machining will be possible in digital space. The impact will be immeasurable.



Noda

Regarding Surface Estimation, we currently use servo data from dry runs and analyze information included in this data to estimate the machined surface as Professor Shirase pointed out. As the next step, we plan to obtain the features of the actual machine from servo data to make the virtual machine more similar to the actual machine, and estimate the actual machined surface only through machining by the virtual machine.
We hope to make Surface Estimation available in a wide range of applications including collaboration with CNC simulation technology. As Professor Higuchi mentioned, the Digital Twin concept is already quite common. For example, our CNC operations include a process to check the program operation using a simulator. This is an existing example of collaboration with digital technology. So it can be said that this concept is nothing new. However, I believe the potential of Digital Twin has increased because the network technology and data-oriented technologies, including IoT and AI, have recently advanced and have become more effective.
The scheme of the network is critical to process real information in the digital world. The importance of an edge platform such as FIELD system will further increase, for example, to link the real world and the digital world to digitally reproduce real data. FANUC will strive to improve not only machining performance, but also to contribute to optimizing manufacturing sites and offering unprecedented conveniences, by introducing the concepts of DX and Digital Twin to the life cycle of machine tools.
Thank you.

President Yamaguchi: Thank you. Now, Professor Hideki Aoyama, please share your thoughts with us.

Professor H. Aoyama: Hello, everyone. I am Aoyama from Keio University. I really look forward to FANUC's Open House every year. Thank you for inviting me again this year.
This is your first online Open House. I have never attended an online exhibition and was wondering what it would be like. Once I actually participated, I really enjoyed it because I was able to spend time seeing a variety of exhibits other than those of my specialty in a calmer atmosphere than usual. I understand that it was inevitable that I could not talk about what I noticed on the spot, exchange opinions, and get an immediate response, but that is the trade-off, I suppose. Under these circumstances, I appreci-

Professor H. Aoyama

ate that FANUC organized this meeting to exchange opinions today. As my specialty is FA, I will talk about what particularly drew my attention regarding individual FA technologies.
I would like to begin with the implementation of the high-speed CPU. This CPU has 2.5 times better small segment processing performance, about 1.8 times better macro processing performance, and twice as many look-ahead blocks compared with previous models. I was impressed by this tremendous performance. Small segment processing performance that is improved 2.5 times is particularly interesting. I have high expectations that this function will achieve high speed and high precision in machining curved surfaces, such as in machining the body mold for the outer plate of an automobile. I would like to know of some machining examples where the high-speed CPU is effective. I expect, for example, that the curved surface of the mold for the outer plate of an automobile or very complicated minute parts, such as aluminum die-cast molds, can be machined with high speed and high precision.
This may sound like an amateur, but I look forward to the possibility that the combination of the functions of this high-speed CPU, a high-precision encoder, and a high-precision servo will increase the precision of skiving gear machining. Although skiving gear machining has already been put to practical use, it is still difficult to apply it to the production of top quality gears. I believe this technology can be used for these applications.
Next I will move on to the Digital Twin concept. Although it was mentioned that the Digital Twin concept is just another name for an existing technology, the term has a feeling of excitement and I personally have high hopes for it. It would be ideal if the boundary between the digital world and the real world became indistinguishable. For this to happen, it is important for FANUC to work with developers of CAD, CAM, CAE, and other related software. I think that this will also enhance the usefulness of FIELD system.
I also believe the state of a real factory can be accurately replicated in the digital world to significantly improve quality in the digital world, by relocating information from servos in the real world into the digital world with technology that is the area of FANUC’s expertise. I hope that you will put the Digital Twin concept to specific, practical use soon.
With Digital Twin, I have very high hopes for the function that recognizes servo position information using the servo viewer and then estimates with high precision the machined surface similar to the one during actual machining. If the machined surface can be inspected to fix faults before actual cutting, it will be a strong advantage especially for mold manufacturers. The ability to develop this function is the strength of FANUC, as a supplier of CNCs and servos. If you further develop this technology to reflect mechanical characteristics such as the torsional stiffness of a ball screw as well as the bending, wear, and vibration of a tool to the movement of the machine tool, in addition to servo information, the tool will be able to realistically simulate the machined surface, which should prove to be an indispensable tool for mold manufacturers and machine tool builders. It would be superb if this technology enables the prediction of faults on the machined surface so that machining conditions can be modified beforehand.
This is also the subject of the mold machining technology study group in the Japan Society for Die and Mould Technology, which I am in charge of. At mold machining sites, aside from unexpected scratches on the machined surface, the precision of the characteristics of a mold shape and character line, as well as unexpected machined surface aspects are the focus of much attention. I also heard that the smoothness of the grinder used by workers at mold machining sites is also included in the evaluation of the machined surface. So, if this simulation can assess the machined surface in advance, it will be a very effective tool.
Now, let me talk about Fine Surface Technology. In this area, I am keeping an eye on the optimization of machining programs. Although this is probably possible in principle or in theory, the relationship between real machining and feedrate must be optimized to solve the problem of deceleration resulting from acceleration/deceleration control because the minimum setting unit is 0.1 μm to 1 nm. I would like to have this optimization be automated.
I also heard that the target form is estimated from a rough discrete point, in other words the zero crossing point, using CAD data. I presume that the successful combination with Digital Twin functions will play a vital role. The function to display the machined surface in three dimensions based on FANUC’s Servo Guide information, and estimate the form to be machined is also exceptional. The difference between the estimated form and the required form shown in CAD is equivalent to the motion error. If the path can be automatically corrected based on motion error information, machining precision will further increase.
The fourth topic is AI Servo Tuning. This function automatically tunes the gain filter and feedforward parameters along with acceleration/deceleration parameters. The benefit of this function for machine tool builders is obvious. In addition, the use of AI Servo Tuning is very effective for users of machine tools in general if the gain filter and acceleration/deceleration parameters can be automatically optimized based on the weight of the form to be machined, the purpose of machining, and other conditions. So, I have expectations for this function to also be provided to machine tool users at large.
The fifth topic is Fast Cycle Time Technology. Although this technology is realized by applying the tool center point control technology for 5-axis machining, high dynamic turning is really interesting and probably highly effective in some applications. I am also surprised to hear that the speed of AI contour control II for lathes has doubled.

To conclude, although this is not related to FA, from the whole exhibit video, it was interesting to find that FANUC has adopted the optimum topology design in designing the Robocut to reduce thermal deformation while sufficiently strengthening machine rigidity for high precision machining. Although optimum topology design is useful in theory, the form would be designed without considering the manufacturing method.
It may work if you produce a single product with a 3D printer. However, if casting is used in production, manufacturing of casting molds and mold cores would be extremely difficult. I heard that FANUC has adopted this technology in the mechanical design. I am very interested in how you have actually adopted topology optimization. I would really appreciate it if you would explain it when you have time.
That is all from me. Thank you.

President Yamaguchi: Thank you, Professor Aoyama. General Manager Iwashita, who supervises software development, will answer your questions.

Iwashita: Professor Aoyama, thank you very much for your comments on a wide range of topics. Regarding the Digital Twin concept, our development, while placing importance on real world performance, was oriented to improve performance using digital technologies. The results were presented at the Open House, as you indicated.

Iwashita

The high-speed CPU that Professor Aoyama mentioned will play a major role for a while as the speed of conventional processors was a bit unsatisfactory in some real world scenarios.
In the digital world, feedback is presently displayed, as mentioned earlier. We plan to develop this to perform simulations without operating the machine, or to simulate the mechanical system, tool status and so on, as Professor Aoyama pointed out, and compare simulations, feedback data, and actual machined surfaces to locate the cause of any problems and improve precision. We would appreciate your advice on the details.
Thank you.

President Yamaguchi: Now, we would like to hear from Professor Takagi.

Professor Takagi: I am Takagi from Tokyo Institute of Technology. Thank you for inviting me today. As my specialty is analog integrated circuits, I am a complete amateur regarding machine tools. I did not see the online Open House thoroughly, but I would like to tell you my impressions from what I saw.


Professor Takagi

As Professor Aoyama noted, FANUC has improved machining precision and machining performance and achieved acceleration with AI servo tuning and AI thermal displacement compensation. FANUC has also further enhanced FIELD system that it launched several years ago, and has also started a digital utility cloud. I also came across keywords such as “AI,” “IoT,” “cloud,” and “machine learning.” Regarding FIELD system, I hope that the data that is currently being gathered becomes big data, so that many applications will become available.
Everyone probably associates words like “AI” or “IoT” with the word “digital.” The government also established the Digital Agency. As an analog circuit specialist, I feel out of place because it seems like the whole world is going digital.
However, an analog signal is always required before you can make a digital signal. Signals in the natural world are analog signals on a macro scale. Signals human beings can feel are also analog signals. Although digital signals are very easy to handle, the bridge for conversion between analog signals and digital signals is indispensable. This is also true for IoT. The initial sensing part is very important.
Sensing micro signals is a strong point of analogue circuits. I was most interested in collaborative robots at this year’s Open House. As you know, collaborative robots detect contact with people. How to capture micro signals while differentiating them from surrounding noise is a major target.
FANUC has consulted with me before about how to improve a circuit they devised. I was considering reducing the number of parts of the circuit to improve the circuit as much as possible, when an assistant professor at our university who attended the meeting, proposed a completely different idea (details omitted). In his proposal, the circuit itself was nothing new, but the advantages of digital signal processing and the features of analog circuits were sufficiently considered, as the assistant professor was familiar with digital circuits, digital signal processing, software, and of course, analog circuits.
What I learned from this experience is that noise reduction is quite difficult if you only have knowledge about analog circuits, even if you are an expert. Although noise always gets mixed in the detection, amplification, and AD conversion paths, the path where noise enters is shortened in the circuit that the assistant professor proposed, and this circuit, which is simple, converts analog signals into digital signals. This made me realize that noise reduction is difficult unless you know about systems, even if you are familiar with analog circuits.
That is all from me.

President Yamaguchi: Thank you, Professor Takagi. General

Manager Hashimoto, do you have anything to add?

Hashimoto: I am Hashimoto from the CNC Hardware Research & Development Division. Professor Takagi has helped us in many different ways. Thank you.
When developing hardware, it is actually not so difficult to design a digital circuit. We only have to design it according to rules based on reliability. The biggest challenge is in integrating the sensing part, which is increasing in importance significantly in recent years, especially the high precision input of micro analog signals to the digital world. We consult Professor Takagi about these circuits as well. (details omitted)
The sensing technology will remain critical to AI, IoT, and robot applications. We appreciate your continuous support.
Thank you.


Hashimoto

President Yamaguchi: Thank you. Next, Professor Hori, please share your comments with us.

Professor Hori: I am Hori from Tokyo University of Science. I reached the mandatory retirement age and left the University of Tokyo last March. In April, I started working at the Noda campus of Tokyo University of Science and everything is going well. Classes are being held face to face for the most part. The atmosphere is young and bustling with many students in their late teens. I cycle along the Tone Canal. I study ways to supply power during driving and wireless power supply for electric vehicles, which has suddenly started gathering attention.


Professor Hori

I accessed your Open House several days ago. I first saw the outlines at the seminars and then saw all the exhibits while reading the technical documents that you gave me. It took a whole day.
Because this was not really at the venue, I could not see actual products. Still, I have visited your Open House multiple times and know the atmosphere and scale quite well. Because there are constraints on time and stamina, I usually was guided to exhibits close to my specialty at the venue. This year, I was able to see all exhibits. As a result, I was able to see things I had not known about for a long time, which was a real eye-opener.
FANUC has really emphasized not only its core technologies such as FA, Robot, and Robomachine, but also activities to support them such as IoT, Service, and FANUC ACADEMY. I was made aware once again that these were combined to become a large force that has made FANUC what it is today. You have a tradition built over time that cannot be created overnight. I am impressed that FANUC keeps such a long distance from shortsighted targets such as making money, which is the stance of not a few companies. I remember the video on an Italian company. That was great.
On the other hand, I was wondering if FANUC properly keeps track of the latest trends in the academic world in addition to the great technologies you have developed, for the fundamental technologies of FA, Robot, Robomachine and other areas. From my viewpoint, for completely new areas such as IoT, your stance was to study as a beginner. At present, your efforts have now completely paid off, which is awesome. However, when it comes to fundamental technologies, it cannot be denied that FANUC has concentrated on developing technical skills internally from the past, and has not been much interested in the outside world. Though the expression may be unpleasant, FANUC was a "closed" entity. Although FANUC is completely different now, your basic sprit seems not to have changed much. Of course, this is not a bad thing in the sense of being unique and autonomous.
For example, customer training accounts for almost all of the videos introducing the ACADEMY. There was no explanation on how FANUC adopts the latest information from the academic world or how information is released from FANUC. You may say that "this is not the objective of this Open House." However, I still think that the fact that FANUC assists its executives in getting doctorates and closely works with universities is useful, especially in increasing the trust of overseas customers and hiring excellent students in Japan as well.
Some may think that basic technologies such as servos have matured almost completely, and room for improvement is left only in using AI in compensation or learning such as DL. But this is not true. Control theory and control technology have advanced greatly over the past 20 to 30 years, many of which would be helpful to FANUC. If you strengthen your limbs and use your clever brains, you will probably be the strongest. Moving a weak body with a sophomoric brain has its limits. There is a linguistically paradoxical trend implying that you are not human if you are not AI. But I think there is much more. Please maintain your tough, uncompromising attitude.
That is all from me. Thank you.

President Yamaguchi: Thank you for your frank and honest opinion, Professor Hori. Next, we would like to hear from Professor Matsubara.

Professor Matsubara: I am Matsubara from Kyoto University. Because other professors have already talked about general matters, I will stick to specific topics. About the online Open House, although you can make confirmations by going back, I


Professor Matsubara

felt a bit frustrated about not being able to immediately ask questions to the exhibition staff. I am going to share my thoughts based partly on my assumptions. If I am wrong about anything, please correct me with your compensation and control, which FANUC excels at.
I will bring up three points with a focus on what interests me now. I assumed that everyone would mention Digital Twin, but my interest was in the machined surface simulator. My first thought was that it is crucial to improve its precision and level of sophistication. Hearing that the command value and servo value are used in this system, I imagine that the originally intended surface and the surface resulting from the change in movement arising from some aspect of the machine are distinguishable. That is, the surfaces which are affected by the characteristics of the machine are identifiable. Examples include a wide range of command values such as an ideal command value, command value which includes machine acceleration/deceleration, and a command value that includes compensation values for machine friction among others. Because this can be a headache to engineers and operators, it is great that these can be separated.
Next, as an extension, the current simulator probably only considers kinematic axes without recognizing the position of the cutting tool edge of the spindle. If, for example, the shape removed by the cutting tool of an end mill can be recognized, this would be extremely interesting. As Professor Hideki Aoyama mentioned earlier, sensory evaluation is conducted during mold machining and so forth. Although our doctorate students create many different machined surfaces and conduct sensory evaluations to check them, the desired roughness is sometimes judged to be unacceptable and vice versa. This is due to the shape left on the machined surface after the tool passes through it, but that is Professor Matsumura's field of expertise. It would be fantastic if this could be calculated. Although mechanical phenomena, such as colliding, slipping, and vibrating, increase complexity in reality, knowledge of at least the surface, before these phenomena occur, will give us a really important clue to understanding the machined surface. The doctorate student mentioned before is studying how people make judgments and the basis of their judgments by calculating the intensity of light just before it enters the human eye after diffusing off a machined surface. It would be very interesting if the surface created with the machined surface simulator can be analyzed.
In this context, I have high expectations for the synchronous spindle motor. Because the induction motor handles slide control, it is really nice that the speed can be properly controlled in the synchronous motor. For example, if the tool edge of the rotating tool does not cut into the machining surface at the same fixed time, the profile of the machining surface deforms. This is because the phase changes. Researchers such as Professor Hirogaki at Doshisha University and Professor Ihara at Osaka Institute of Technology pour all their energy into predicting the changes to match the phase of the profile of the machined surface, which is quite a chore. Synchronization between the translational axis and the spindle significantly makes this easier. Matching profiles of the machined surface also affect subsequent processes, including ease of polishing. Therefore, I presume that the synchronous spindle motor will develop into many different forms. "Things and Ideas" were mentioned earlier. In my opinion, something such as sensitivity will be added to bring about "value."
As a last point, the temperature sensor unit was interesting. I remember that FANUC introduced a vibration measurement device two years ago that provided a 16-bit high-speed response. This year, FANUC has targeted thermal displacement, which is also very promising. We are also currently creating many different thermal models on the machine side. The hardest issues are contact thermal conduction and heat transfer. Because a machine tool supports heavy items with a guide, the heat flow keeps changing depending on the position of the guide. Just measuring the temperature is of no use. You must completely identify the current positions of the spindle and table to understand the overall heat flux. For example, you should find optimal test patterns to identify the heat transfer coefficient for the contact surface, which is most difficult.
I would like you to focus on this area because the results can be applied to create a mechanical design which is good in terms of temperature.
That is all from me.

President Yamaguchi: Thank you, Professor Matsubara. Now, General Manager Fukuda from the Servo Research & Development Division will respond to the comments of Professor Hori and Professor Matsubara.


Fukuda

Fukuda: I am Fukuda from the Servo Research & Development Division. Thank you for your comments, Professor Hori and Professor Matsubara.
First, Professor Hori pointed out that FANUC does not properly keep track of the latest trends in academia to add to our technologies. We will take this comment to heart and make improvements where necessary.
Regarding servos, we introduced servo tuning using AI this year. From my understanding, Professor Hori's point was that we need to make sure we have our control theory right. Devices

also evolve in terms of acceleration and other aspects at the same time as control theory. We will seriously pursue control that is suitable for devices as they evolve. Professor Hori has also commented on power devices such as SiC every year. We will also continue to develop new products, watching the trends in SiC and new gallium-related devices in the industry. We appreciate your continuous guidance.

I am also grateful for your comments, Professor Matsubara. To begin with, you are correct in that we have not yet been able to recognize the shape of the cutting tool during the first machined surface estimation. Currently, we can track the traces of a cylindrical tool. We think that coordination between the expertise of a CAM manufacturer and the part FANUC should be in charge of need to be well balanced. We also realize that there is a difference between high precision and surface quality and are aware that even if high precision is achieved, it may fail in sensory evaluation.

In addition, we will consider whether to leverage the synchronous spindle motor to ultimately control the phase of the cutting tool edge. Currently, we are conducting comparative verification of a synchronous spindle motor and an induction spindle motor. The verification has revealed a variety of facts including the pros and cons in machining, the pros and cons that depend on each workpiece, and differences in principle. In the Robodrill, we are promoting the tapping spindle equipped with a synchronous spindle motor, with focus on reducing cycle time. We will consider the viewpoints the professors shared with us today as well.

Thank you.

President Yamaguchi: Thank you. Now, Professor Tanaka, please let us hear your opinion.

Professor Tanaka

Professor Tanaka: I am Tanaka from the Joining and Welding Research Institute of Osaka University. This is the first time that I have been invited to this round-table talk. Thank you for inviting me. I gained a lot of inspiration seeing this online Open House.

I believe I am supposed to comment on FA, but I am interested in robots because my specialty is welding engineering. That is why I saw the laser robot exhibit first. I was impressed with the laser scanner presented at the exhibit. Welding technology is really a conglomeration of several technologies. Among them, the three-dimensional Galvano scanner, robot, laser oscillator, and PC simulation software are all configured as a system with FANUC products only. This refinement embodies an advantage of Japanese manufacturing, which is combining technologies complete in one package. Furthermore, FANUC is involved in welding technology from the user's viewpoint. This is symbolized by the integrated linkage between ROBOGUIDE, Galvano scanner, and robot. In particular, complicated welding patterns can be checked on the 3D screen, and the Galvano scanner and robot can be integrated and taught at the same time. While this used to be a very troublesome task, it can be easily performed by anyone visually. That is great from the user's perspective.

In the hardware area, I found the "wobbling function" to fluctuate laser beams to be useful. It is noteworthy that the wobbling function can be added to the free curve of laser irradiation. The gap width is very challenging when welding various shapes of three-dimensional fittings as it varies by location. Laser beams are advantageous in that they are finely focused. The finely focused laser beam becomes a heat source that expands spatially at an hourly average and changes into a tailor-made method for smart welding. These are coordinated naturally. As a result, welding is possible even when there is a difference of 30% in sheet thickness. I particularly found it great that fume does not stick to the end of welding beads even when a galvanized sheet is welded. The video of the beautiful bead was impressive. Little fume means little metallic vapor (also known as "smut" in the welding field) from base materials such as zinc or the weld pool. I was surprised to see how skillfully controlled the temperature in the weld pool was. Distortion and deformation resulting from welding are also probably kept low because heat input is controlled.

Now, let me talk about the OCT (optical coherence thermography) sensor. This sensor measures the penetration depth during welding in real time and controls the quality of the welding part at the same time, making difficult welding very easy. As a welding engineering expert, it has been my dream to ultimately make reliable welding possible just by pressing a button, without requiring training and knowledge. This laser scanner is very close to making this dream come true.

I was also inspired by the hairpin welding of copper wire. The welded section is formed very stably by irradiating the ends of two copper wires with a laser to effectively form a weld pool through high-speed laser fluctuation and reliably bridging them. In particular, spatter is reduced effectively during welding. Other professors have said that hardware refinement is critical to handling this high-speed fluctuation in a laser beam, and I think this technology is top class in the world, in this sense. In particular, as the achievement of carbon neutrality is an important challenge for Japan, the role of electric motors for automobiles, power generation, or other purposes is becoming extremely important. In this context, this hairpin welding of copper wire proposes a stable welding technology with high quality and high efficiency in manufacturing electric motors, largely contributing to society.

Lastly, I was impressed with your Digital Twin concept in FA, even though this is not my specialty. Because Digital Twin is

also mentioned in the 6th Science, Technology, and Innovation Basic Plan, it seemed to me that FANUC is advocating a new form of "manufacturing society" that Japan is aiming for in a certain sense. As I recall, the Digital Twin technology for subtractive manufacturing was introduced in the FA area at this year's Open House. I hope that FANUC will develop this technology for welding.
Additive manufacturing (AM) will be important in addition to subtractive manufacturing for creating machine parts in the future. There are many different AM methods. Even when the material is metal powder, welding technologies accumulated over the past is applied. However, casting technologies should not be replaced simply by adding materials. I hope that FANUC will create values which are only possible with AM. In this sense, I would like FANUC to thoroughly apply the Digital Twin concept to welding technology. That would lead to new developments in the future. It would be best if you could design and manufacture a new structure only possible with AM in cyberspace and return that information to physical space. Integration between cyberspace and physical space as well as integration between subtractive manufacturing and additive manufacturing (AM) will become the new foundation of manufacturing in the future. I look forward to FANUC's continuous development.

President Yamaguchi: Thank you Professor Tanaka. I greatly appreciate your joining this round-table talk for the first time. Your comments on welding and other topics were really refreshing. We are very grateful. Now, we would like to hear from General Manager Nishikawa from the Laser Research & Development Division.

Nishikawa: I am Nishikawa from the Laser Research & Development Division. Thank you Professor Tanaka. We are very flattered to hear so many positive comments from you. The laser scanner you mentioned was made with the aid of many other research & development divisions at FANUC, not just by the Laser Research & Development Division. We worked on it for a long time, repeatedly used it in the company, and thoroughly checked it in reliability tests before commercialization.


Nishikawa

We will probably receive many different requests once this is commercialized. In addition, changes including new usage, new workpiece materials, and new workpiece shapes will appear. All of our research & development divisions will work together to improve the laser scanner.
That is all from me.

President Yamaguchi: Thank you. Now, Professor Sasahara, please give us your comments.

Professor Sasahara: I am Sasahara from Tokyo University of Agriculture and Technology. Thank you for inviting me to this round-table talk again. This is also the first time that I attended this type of online exhibition. I saw many different exhibits and they each drew my attention because they were so interesting. Because the other professors talked about many different topics around FA, I am only going to speak about a few main points. As I study cutting and wire arc additive manufacturing (WAAM), I am going to mainly talk about matters related to them.


Professor Sasahara

First, regarding the improvement of performance to process minute blocks of NC equipment, I have the impression from exchanging information in academic meetings or other occasions that, unfortunately, even among engineers specialized in cutting, there are few who correctly understand what the suitable small segment length is when cutting a curved surface with an NC. Surprisingly, not many engineers understand that the shorter the small segment length, the smaller the angle changes, which results in a decrease in deceleration and enables high-speed motion. Many engineers seem to retain the memory of a decade ago when the capability of NC equipment was still low and say that it is permissible if the old small segment length falls within tolerance or, on the contrary, a longer small segment length decreases the amount of data, reduces control points, and enables high-speed operation. Universities also conducted related studies and the results show that a shorter small segment length in the range that NC equipment can process results in higher speed and improves precision. Therefore, the direction is exactly the same as that of FANUC that was presented at this Open House. I believe education and promotion about how the line segment length should be set are required mainly for machining engineers and CAM operators, although academia should also be responsible. If education and promotion is not carried out, even if the NC equipment is increased in speed, it might not be fully effective for enhancements in speed and precision if the input NC program is not appropriate.
Another issue in this context is the optimization of machining programs. I carefully examined a slide and found that the interval between control points optimized in NC equipment was smaller than the interval according to G code. I assumed that this optimization was internally addressed on the NC. If the user has no need to be aware of acceleration and precision enhancement, it would be a huge step forward.
Next, regarding AI servo tuning. As I recall, the feedforward

value was a target at the last Open House. I felt there were advancements this year with the addition of the gain filter and acceleration/deceleration. According to the video, parameter adjustment takes 30 minutes for gain, 30 minutes for feedforward, and 60 minutes for acceleration/deceleration, which is a relatively short time for identification. I was curious to know what operations are performed for identification. Parameters can be tuned to be optimal to meet the needs of the actual machining situation. For instance, in mass production, optimization can be focused on the precision of curved surfaces, or the speed for machining parts, or the different weight of workpieces. This would offer high values to users.
The new NC for lasers was also interesting. It was explained to me that FANUC's high-speed, high-power laser can immediately be mounted on a machining center or lathe with this NC. I understood this to mean that a machine tool can be readily developed that combines subtractive manufacturing, laser machining, and laser welding. If lasers can be controlled as desired, they can be applied to DED (Directed Energy Deposition)-type additive manufacturing (AM) equipment where powder or wire is supplied and then melted and layered with laser energy. Though FANUC's current lineup does not include AM equipment, the technology is feasible. I look forward to the development of a purely made-in-Japan combined laser/cutting machine or AM machine. The development of a machine combining laser subtractive manufacturing (cutting) and DED-type AM equipment (multi-function machine) is also feasible and would be exciting.
I also found adaptive control welding with the arc welding robot very interesting. As I recall, even if the sheets to be joined are slightly misaligned, the robot detects the misalignment and then welds them appropriately. There are some issues concerning the wire arc AM (WAAM) using arc welding. For example, the layer height cannot be controlled precisely, and with sloped walls, molten metal is pulled by gravity to solidify unevenly. As a result, in certain cases, molding cannot be performed as desired. With this technology, however, the previous layer can be identified so that the next layer can be placed in a manner to compensate the former layer to achieve the correct form. This technology is very useful not only for welding but also for wire arc AM. As reference, wire arc AM is possible with the combination of a welding robot and MIG welder.
As a last word, let me comment on robots. Because I also research cutting, I have an interest in robot milling as well. I think that applications and fields where robots are used for subtractive manufacturing, such as cutting, will gradually spread in the future. Because there are limitations in hardness and precision compared to machine tools, machining efficiency and precision will not be as good. However, I think that milling applications with robots will start such as with the machining of materials of large parts or materials with small cutting resistance. I also have hopes for such developments, though they may be already in progress.
That is all from me. Thank you.

President Yamaguchi: Thank you, Professor Sasahara. Because Professor Sasahara has asked questions on many different topics, the relevant departments will answer them separately. Now, we would like to hear from the last speaker on FA. Professor Shinno, please let us hear your comments.


Professor Shinno

Professor Shinno: Thank you for the introduction. I am Hidenori Shinno. First, allow me to use this opportunity to inform you that I was appointed President of Polytechnic University, which is under the supervision of the Ministry of Health, Labour and Welfare, on April 1 this year.
Presently, I regularly organize workshops on specific technical topics to exchange information between experts and other attendants as a facilitator of the industry-government-academia technology advisory panel of the Japan Machine Tool Builders' Association (JMTBA). The results of a recent survey of corporate members confirm that many machine tool builders are interested in ICT, AI, Digital Twin, CPS, and DX as technical challenges, in addition to conventional technical topics, namely, thermal deformation and chatter vibration in machine tools.
The exhibits at this year's New Products Open House Show 2021 cover all the above-mentioned keywords and provide a timely source of information that is exactly what customers need. In other words, FANUC devotes itself to dealing with the technical challenges which machine tool builders, who are your main customers, currently have the most interest in. For example, FANUC introduces application examples and provides practical information for concepts such as "Digital Twin Concept of CNC." Customers who visited this Open House could see specific examples of Digital Twin made famous by the media and other parties, and were made aware that most of the peripheral technologies needed to take advantage of the benefits of Digital Twin are now readily available.
However, as Professor Higuchi pointed out, the concept of taking data in physical space and reproducing and simulating it in digital space is nothing new. So, more than a few people may wonder what the differences are from previous technologies. In the future, we should make Digital Twin dynamically interconnect physical and digital space so that they complement each other, such as by using ever-changing information obtained by sensors on phenomena that are not understandable in physical space, and reproducing and estimating these phenomena in digital space in real time, to execute the required process. I believe that such Digital Twin technology can be used to

develop self-diagnosis functions of production systems, and even self-repairing functions, which are considered to be quite difficult.

At Polytechnic University, we research and develop the learning factory, which is a Cyber Physical Production System (CPPS) for education and training of manufacturing to keep up with the Fourth Industrial Revolution. We may ask FANUC and the professors who are here today for your cooperation and support in the future, and would appreciate your consideration.

Now, let me summarize my impression of the exhibits as a whole.

(1) From a quick look at the exhibits at this Open House, I got the impression that the product names cannot be easily associated with the hardware and software products. Perhaps FANUC is too serious-minded. In my opinion, more user-friendly names are preferable. Examples are “ZDT,” “iRVision,” “QSSR,” and “FabriQR Contact.” It is very difficult to intuitively guess what these products are from these names. Especially, regarding the product names of Robonano, which are “α-NMiA” and “α-NTiA,” I presume “M” and “T” stand for “machining” and “turning,” but as these letters are in the middle of the product names, it is difficult for customers to easily differentiate the two types of products.

(2) Although there were exhibits that emphasized “compactness” here and there, I did not see any clever way for letting visitors get a feel of the size of the products. For example, it was hard to see the extent the servo lineup has been reduced in size compared to previous servos.

(3) Although “new” is repeatedly used in many exhibited products, which parts are new and in what sense they are new are not sufficiently explained and their selling points are not clear. You should distinctly show the advantages such as “the product was newly developed for this Open House,” “the product has new functions not available in past FANUC products,” “the product is innovative and unique to FANUC,” or “the product achieves the highest performance ever.” I believe that you could effectively appeal to customers by explicitly showing what is new in the products.

(4) Robots will be increasingly installed and deployed in the production environment in the future. I could see that FANUC is really focusing on collaborative robots at this exhibit. The performance improvement of the collaborative robot itself including speed and precision, and intelligence are expected to be enhanced significantly. In the 1990s, research was conducted from time to time on collaborative control of multiple robots, with the main focus on using robots to do tasks humans were doing. The results of such studies have outgrown the realm of laboratory research and are now being applied to actual production systems. It has been also pointed out that the productivity of Japanese manufacturing, which was considered high, is actually low. Given this background, I hope that FANUC will make new proposals for practical industrial applications, for example, to streamline complicated tasks that were impossible for human beings to carry out, or to perform extreme tasks that are difficult for a single robot, by using multiple collaborative robots.

That sums up my personal impression on the New Products Open House Show 2021. In ending, let me make one more comment even though it is not a direct impression of this Open House. FIELD system was the centerpiece of past Open Houses. However, in this year’s exhibit, FIELD system was slightly toned down. FIELD system is positioned as the underlying technology for realizing CPS and CPPS, which machine tool builders will be interested in the future. I hope that FANUC will establish and develop implementation technologies to skillfully integrate mathematical, data science, and AI technologies in FIELD system.

Every year, I come to your Open House, wondering what innovative technologies you will present. I look forward to your future Open Houses.

President Yamaguchi: Thank you, Professor Shinno. Now, Chairman Inaba will wrap up the part focused on FA.

Chairman Inaba: Thank you, Professor Sasahara, Professor Shinno. I had assumed that Professor Sasahara was going to talk about AM and was a bit surprised to hear him talk about the Open House as a whole. However, as Professor Sasahara’s range of research is broad, I appreciate what he noticed and the advice he has offered, not limited to AM. Thank you very much.

Y. Inaba

Regarding minute block machining, though precision is top priority for parts machining, for machining the free-form surface of molds, achieving good surface quality is the biggest hurdle, and I feel that we are still halfway in obtaining satisfactory results. Professor Shirase has given us guidance on these technologies. What is important is retaining the enormous amount of CAD data up till machining to create a smooth cutter path. I think that we have managed to take a step forward through our research. We will further refine our technologies in this field.

In addition, no matter how good the commands are, unless there is tuning, the machine cannot exert maximum performance. We are grateful that AI Servo Tuning gathered attention. We are making efforts to build a function that enables everyone to perform near optimal tuning quickly and easily, although there are still limitations. Regarding AM, we did not exhibit AM using wires, which is Professor Sasahara’s specialty this year, but we are developing the underlying technology, and would appreciate your continuous support.

Now, let me thank Professor Shinno as well. I have also been recently appointed as Chairman of JMTBA and look forward to your cooperation. We would appreciate it if you would help in developing new machine tool technologies, especially application of new materials and use of IoT technology.
Professor Shinno also mentioned a wide range of topics. Regarding the Digital Twin concept, I think that what we aimed for back in the IMS project is in fact being promoted again in the world using a different term and appearance. One could say that we are learning from the past. We will develop this technology in order to bridge physical space and cyberspace, and produce reliable results in the world of simulation. We will target prototyping and machining which bear fruit, rather than just tout the term.
Lastly, though some of your comments were rather disheartening, they were also very stimulating. Actually, the main theme of this year's exhibit was ease of use. We tried to develop and exhibit products from the user's standpoint, but your comments brought home to us that we still see things only from the developer's perspective in our own world. We intend to develop functions, determine product names, and perform other activities from the user's standpoint. We appreciate your continuous support.

ROBOT

President Yamaguchi: Now, moving on to robots. First, we would like to hear from Professor Asama.


Professor Asama

Professor Asama: I am Asama from the University of Tokyo. Thank you for inviting me to the online New Products Open House Show and round-table talk today. I have been to your Open House several times, but because last year's Open House was canceled, it felt like a long time since I saw your exhibits. I saw various displays, technical seminars, among others, but as others have said, I was not able to interactively ask questions face-to-face. Still, it was quite convenient since I was able to see many different exhibits while sitting in my chair.
I will make a brief comment mainly about robots. Although I had the strong impression that FANUC was a manufacturer specialized in hardware and control, after seeing this year's exhibits, I got the feeling that the company is changing into an all-round manufacturer that provides digitization, intelligence and services. I now have the strong impression that FANUC integrates state-of-the-art technologies such as ICT, IoT, machine learning, and AI, to further enhance the value of robot products and services and boldly attempts to develop new global businesses.
Specifically, various types of robots are commercialized for many different applications in a wide range of manufacturing processes. The lineup is really rich and fulfilling. FANUC has developed and commercialized a wide range of products centered on highly reliable and robust hardware, along with high performance and safe control systems such as can be seen in collaborative robots. These include sensing systems such as vision sensors, laser sensors, and laser scanners up to a new end effector called "Soft Gripper." Furthermore, FANUC comprehensively is engaged in a wide range of businesses among which are the use of intelligence and systems for bin-picking and unloading, design support tools such as ROBOGUIDE, status monitoring, failure prediction, failure diagnosis, maintenance, and other services that use IoT, networks and AI such as Zero Down Time, and education using practical training materials. I feel that FANUC is stably advancing every year.
In particular, amidst requirements to prevent the spread of the new coronavirus, an environment in which efficient production is possible without close human contact is in demand in the manufacturing industry, with attention on life with and after COVID-19. I am sure that FANUC's robot technologies will contribute to meeting these needs. As the world aims to build a human-centric society known as "Society 5.0," these human-focused production systems will be increasingly important in next-generation manufacturing. As technologies to support people in various ways in coexistence with human beings are expected to play an important role in the future, FANUC's collaborative robot will become more vital. As you may know, the collaborative robot CRX received the Minister of Economy, Trade and Industry Award at the Robot Award, last year. I would like to express my sincere congratulations.
For the past two years I have been serving as the director of Research into Artifacts, Center for Engineering, which was just set up in the School of Engineering. I have talked with people from various manufacturing companies. Many of them have a lot of concerns including the aging society with a low birth rate, labor shortage, and maintenance of international competitiveness as the social environment dramatically changes. In addition to automation, I found it extremely important to increase the capabilities of manufacturing sites, that is, continuously develop people, to solve these challenges and maintain competitiveness.
FANUC stands out with its developments from the customers' viewpoint. I presume customer satisfaction is very high, but it will be also important to raise employee satisfaction in the future. As the other professors have pointed out, the development of cyber-physical systems and Digital Twin using digital technologies is accelerating and was one of the highlights at this year's Open House. Professor Higuchi said that the term "Digital Twin" may eventually disappear, but the Research into Artifacts, Center for Engineering is now promoting the concept of "Digital

Triplet," taking Digital Twin one step further. The cyber-physical system and Digital Twin are to be leveraged by people. It will be important to turn people's skills and knowledge into explicit knowledge and digital data, and support people's production activities through their use. We would like to work on these challenges through collaboration with companies.
In the future, it will be important to promote service development, efficiency in design and production, rapid improvement, and other goals, based on digital transformation and big data, and at the same time, extract and utilize skills and experience from workers and engineers on site, and use these to build and improve an environment which will support their activities. These should be linked to encourage people's development and growth to make, not only customers, but also employees feel more motivated, more satisfied, and happier.
For this end, it will become even more important to understand the people the system supports and coexists with. Future collaborative robots must understand people, and safely operate while estimating and predicting people's behaviors and intentions. They must also know how they should support people to reduce physical and mental burdens and take action. For example, robots should guide people to reduce human errors, motivate people, or provide a feeling of achievement. I think that these capabilities will be important. It would be ideal if we could further clarify the specification requirements of collaborative robots for understanding people, and position these robots as workers' partners in the manufacturing industry. I sincerely hope that FANUC will continue to advance as a leader in the manufacturing world.
That is all from me.

President Yamaguchi: Thank you, Professor Asama. Now, we would like to hear from Professor Sugano.

Professor Sugano: I am Sugano from Waseda University. Thank you for inviting me today. Congratulations on the triple awards that the CRX received.


Professor Sugano

Speaking of the CRX, I found the video of the CRX interesting and watched it several times as I study robots that can coexist with people. I must admit that I did not actually see many other exhibits, so, I would like to mainly comment on the CRX.
First, as I mentioned two years ago, the design of the CRX is very sophisticated compared with the green robot, which has a very "robotic" appearance. I hope that you will continue to design your robots in this direction.
Regarding specific functions, I saw direct teaching and collaboration with AGVs several times. Due to COVID-19, academic meetings are currently not being held on site either. Exhibitions, which are usually combined with academic meetings, are not being held at all. There is only video streaming at every academic meeting, and we no longer have opportunities to touch new robots directly.
Though I really respect FANUC's efforts to create ingenious videos under these circumstances, actual details of robots cannot be understood via video alone. I imagine that the other professors attending this round-table talk would also very much prefer to directly touch and watch robots move because their own areas of expertise are robots and machines. I also want to show the features of robots such as their movements and their control on the extent of force at workshops, but have found it difficult to convey what they are actually like.
For example, even if you described direct teaching by saying that "it is very soft and very easy to do," many companies and universities would use similar expressions, therefore the differences would not be understood. We have also tried a lot of things to convey the differences in my laboratory. For example, we calculated how much force is actually transmitted to the end of the robot's hand and facilitates movement during direct teaching. Let's assume that instead of a human, a robot performs direct teaching for another robot. If you measure the force at the end of the robot's hand that is performing direct teaching and that force is small and is free of vibration, you can know that the direct teaching is very smoothly executed.
Needless to say, when we will be able to hold face-to-face events again, just touching the robot will be sufficient. However, for a clear understanding of such features in a remote location, where touching the robot is not possible, you must do something extra in the presentation. I have hopes that FANUC can come up with creative ideas. After all, touching a robot will reveal its value. Please consider how to make this possible.
Next, let me comment on AGVs. I heard that FANUC was not engaged in the development of AGVs in the past but has recently started with SCARA robots among others. At this Open House, I saw a video in which the AGV was used for positioning with a machine tool and for actual transport. FANUC excels at precision and vision technologies but does not seem to have integrated them into this application. I think that you can easily develop a movement where an ordinary AGV freely moves, and the machine tool performs high-precision machining without using a clamp or any other tool. I really would like you to consider developing such a system.
Another thing I want to mention is the soft gripper. I saw a very short video of tomato harvesting. I also think that the use of robots in agriculture is vital, and have been involved in research and development of agricultural robots. Tomato harvesting is not easy. The robot may be able to pick and collect tomatoes in a specific environment. However, unlike in a factory, farm goods are natural products and are different in every manner. Robots need to adapt to the environment and meet the requirements

unique to the product. While watching the video, I wondered a bit if FANUC plans to enter into the agricultural industry. If you have conducted other agricultural application experiments, I would really like to see them.
I would like to talk about two more things. When I came to the Open House two years ago, a high-speed picking robot was exhibited. The challenge was to confirm to what extent the robot could conduct the operations of a so-called distributor. I would like to know about the development of this robot because there was no related exhibit this year. Another thing I noticed is that AI technologies were hardly included in the introduction of robots. This may be because AI is already taken for granted. However, I believe that AI will be integrated into hardware in the future and will evolve into a new AI. AI will not be added to robot hardware but hardware will be integrated into AI. This could be thought of as a Digital Twin from another point of view. If you come up with a new AI, that is, an AI integrated with hardware, the robot AI can be differentiated from other AIs.
That is all from me. Thank you.

President Yamaguchi: Thank you, Professor Sugano. General Manager Abe from the Robot Mechanical Research & Development Division and General Manager Kato from the Robot Software Research & Development Division will comment on what Professor Asama and Professor Sugano have said.

Abe: I am Abe from the Robot Mechanical Research & Development Division. Thank you for your valuable comments, Professor Asama, Professor Sugano. I am also grateful that you congratulated us on the awards we received. You mentioned employee satisfaction earlier, and receiving these awards really encouraged all our employees. We are now much more motivated. We ask for your continued support.

Abe

As Professor Asama said, for a long time FANUC provided robot hardware, control, machines, and software, but how they were used was left to customers. Now, we are facing a situation where the usage of robots must be considered in order for them to be installed, or they will be seen as being very difficult to use. We selected ease of use as a theme for this Open House because we wanted to focus on people and examine how people can easily use robots and how each customer wants to use them. The birth of the collaborative robot is also indicative of this. Professor Sugano has helped us a lot. I still remember when you said that the collaborative robot must look good. Professor Asama also gave us similar advice. As a result, the design of the CRX was a major aspect from the beginning, and we are proud to have created something different from our conventional products. However, as Professor Asama said, this is just the beginning. We expect further developments where robots deeply understand people and where one robot directly teaches another robot for mutual assistance, as Professor Sugano mentioned earlier. We would like to evolve our products including the CRX series based on many different pieces of advice.
Now, General Manager Kato will talk about direct teaching, AI and picking.

Kato: I am Kato from the Robot Software Research & Development Division. Thank you for your comments, Professor Asama, Professor Sugano. All of your suggestions, such as making it more natural and easier to use direct teaching and operating a robot without fixing its installation position are important improvements to make it easier for people to use robots. As Professor Asama said, robots that can be used in human-centric production systems are increasingly needed in today's world, which is suffering from the COVID-19 pandemic. We will aim to develop robots that can be smoothly installed in factories where people work, but there are still many challenges to overcome. These include automated setting of welding and machining conditions and further facilitation of teaching. In addition, we have been continuing our research and development of high-speed picking and AI, though we did not exhibit such new products at this Open House. We will work to show you new products and functional enhancements at the next Open House. Please continue to help us in these fields as well.

Kato

President Yamaguchi: Thank you. Now, Professor Sakuma, please let us hear your comments.

Professor Sakuma: I am Sakuma from the University of Tokyo. Thank you for inviting me. My specialty is perhaps a bit different from the specialties of other professors. I study biomedical engineering. In relation to robots, I study surgery assistance robots, treatment support, and bioinstrumentation. In a sense, treatment could be thought of as processing of a living organism.. The other professors have already commented on robots and other subjects, so I would like to make remarks from a slightly different viewpoint.


Professor Sakuma

First, I thought the online Open House was great in that you can take your time and look at things repeatedly as other professors have also mentioned. On the other hand, there was no interaction, though I guess that the professors were able to imagine what they are like to some extent just by watching the videos because they have seen the actual products. This method is very useful in conveying information but there is probably a better way. The manner in which the Open House will be held will change a bit after the pandemic settles down.
I also thought that the collaborative robot that works with people is related to bioengineering. In fact, when I saw a collaborative robot at the Robot Exhibition in December 2019 before the COVID-19 pandemic, I remember thinking that a robot worked with people and was almost like the medical robot we were studying.
The next topic is the vision sensor. The surgical robot used during endoscopic surgery works with vision. The question of how vision is processed is actually very close to the problem we are working on. For example, there is much activity related to using AI for surgery assistance images. Professor Hori said earlier that many different activities are being conducted by academic societies. You might be able to find clues by looking into these activities. In this context, I remember that I talked about the safety of personal robots at a committee chaired by Professor Sugano nearly 20 years ago. I think that the discussion of that time is critical.
Although FANUC explained that safety is ensured because the robot stops when it hits something, I do not think it is that simple. You must work with customers, identify application scenarios, and manage safety risks within those scenarios. I think you will discover several patterns while introducing robots. It would be great if you could roughly categorize efficient applications where safety is reliably ensured, and consolidate case studies.
In addition, when people work with a robot, the robot cannot ensure safety without anticipating people's behavior to some extent. On the other hand, the whole system must recognize what task is currently underway. In fact, this is now a major area of research in the surgery assistance field. We have started thinking about changing the control method based on an understanding of what is presently going on in the surgery process as well as the whole system. When people work with a robot, the robot must guess what actions people will probably take under certain circumstances to collaborate, even if it is inevitable that there will be people that do unpredictable things.
Now, let me comment on sensors. Sensors in this context, more or less mean devices that passively measure events in the physical world. A robot actually has a bunch of moving actuators equipped with many different sensors. Although a force sensor was fitted in the exhibited collaborative robot, I think that it can also collect a response when the workpiece receives a specific stimulus. Excuse me for expressing in bioengineering terms. I think these sensors can also do something like "active sensing." In light of this, you can consider broadening your definition of "sensor" a little bit.
Regarding digital technologies, as you know, remote medical care has started. Because the number of available sensors is limited, the current state of remote medical care is basically just diagnoses via an interview. This means that the manner with which information is collected on that occasion is important. There was a discussion on analog and digital earlier, but digitalization actually means you are cutting off information. In relation to simulation, if interpreted in a bad way, it can be adapted to anything by tuning parameters. In a simulated world, you need verification to confirm that the computing system is reliably calculating the model, and validation to confirm that the model itself is appropriate. I think determining how to develop these processes is a future challenge.
As for the combination of simulation and AI, AI now seems to be thought of as a cure-all. I do not think that this is completely true. Although it is truly crucial that you can logically create the simulator and numerical model in terms of constructive theory, we have no idea about the parameters needed to create such simulators and numerical models for living organisms.
For example, let us assume that there is an average value and dispersion around it. If this does not match with experimental data and there is an inverse problem, AI may be used to some extent as a different approach. While listening to your discussions, it seemed to me that how to adapt the simulator to reality and actual sites is a challenge for the future.
Lastly, although education was mentioned earlier, making things easy to use and creating an easy-to-use system, as emphasized at this Open House, are key propositions from a researcher's point of view. They are good for efficient manufacturing. However, if you pursue ease of use too much, things become too simple, possibly resulting in a situation where you are just going through the motions without understanding the essence of what you are doing. This is probably a challenge that universities must overcome, but I thought it was something we should consider.
From this standpoint, many different kinds of digital data have become available. Although data is presently used based on the current way of thinking, I think that data contains information that provides a lot of potential when viewed from many different aspects. In fact, the data is a gold mine for companies. From a researcher's perspective, you can do a variety of things by coming up with ideas for using the data. I would like you to give some thought to how businesses and universities can cooperate with one another to work on these issues.
That is all from me. Thank you very much.

President Yamaguchi: Thank you, Professor Sakuma. Now, Professor Ishikawa, please share your comments.

Professor Ishikawa: I am Ishikawa from the University of Tokyo. I really looked forward to this Open House because it has been two years since the last one and because the Open House was going to be held online. Like other professors, I was also able to see the entire Open House. As a whole, I saw large advancements in the areas of sensing, processing, actuation, and manipulation. I felt that overall processing, not just processing in a standalone system, but networked processing like that in FIELD system, or how processing is linked with already acquired data, entered into a new level. FANUC has also made large advancements in broadening the existing range of manipulation and actuation through its continuous efforts. My remarks center on sensing.

Professor Ishikawa

I got the impression that sensing is increasingly evolving, not only for FANUC ROBOTs, but across all FANUC products. In particular, it became clear that the ability to precisely capture the real, physical world, plays an important role in improving the functionality of the entire system. This year's Open House introduced the 3D sensor in which I am particularly interested within the area of sensing. Although sensors already existed, the lineup was enlarged and in particular, close range 3D information can now be accurately captured. This means that FANUC has managed to develop sensors that have the specifications that everyone was looking for, and is an indication that sensors have steadily evolved. However, there are admittedly many competitors in the 3D sensor area. Many different groups have conducted development not only for robots but also for the human interface, and in relation to how to take 3D images from a drone or how to capture the flow of people in society. I hope that FANUC will stay focused on its target specifications and functions during development. I believe that reliability and ease of use are features which FANUC should prioritize.

I also saw a demonstration using 3D CAD data. What many people have expected and hoped for is also steadily becoming a reality in this demonstration. Bin-picking was matched with CAD data to accurately determine the gripping position and pick up the workpiece, which was impossible in the past. It is great that these processes can be executed reliably.

In fact, this is not limited to CAD data. CAD data can be used, but data measured actually can be used in place of CAD data. I would like you to keep in mind that measured data can be matched to perform many different tasks.

Regarding the application of visual feedback, two-dimensional visual feedback was used to attach moving tires in another demonstration. I think this is a large step forward even if the demonstration was very simple. Some viewers might have thought: "This is nothing special. It is just attaching normal tires." However, performing this task with vision sensors only without using encoder information is a key point. I tried to find a good analogy. The conventional robot was like a child who just started riding a bicycle with training wheels. The new one is like a child who safely rides the bicycle without training wheels, checking the surroundings with his or her own eyes. In the past, the absolute coordinate system was used to operate the robot and calculation consisted mainly of coordinate conversion. The robot can now smoothly operate without using an encoder, which suggests that control, or maybe just part of it, has shifted from coordinate conversion in an absolute coordinate system to a relative coordinate system. If the robot can operate with the precision achieved under relative coordinate system control, the vision sensor will also have the precision of this control. This is a big advancement. I hope you raise this "child," who can now ride the bicycle alone, until he or she can participate in a road race.

Also, I would like to add my comments about collaborative robots to what the other professors have said regarding sensors. I suspect that collaborative robots now operate mainly by using force sensors. If force sensors are used, however, there is a problem of the robot not stopping until it comes into contact with an object. Replacing these force sensors with vision sensors, or at least proximity sensors or others, will present a challenge. With vision and proximity sensors, it is difficult to cover the whole field of view, that is, create a system without blind spots. If this can be achieved with your ingenuity, the robot will be able to stop before coming into contact with something.

Speaking of the effects of including vision or other sensors, FANUC had a demonstration which showed that visual feedback would allow the robot to check and recognize the gripping position without stopping. This is a phenomenal advancement in spite of how casually it was explained. I have also repeatedly insisted on the importance of stopping neither the robot nor the object at these talks. Now that you succeeded in creating a system that can properly recognize objects without stopping the robot, I hope that you will continue advancing in this direction. It is important to carry out tasks without stopping the robot or workpiece to increase speed in factories in the future.

In other words, the world that people see is limited to the field of vision that enters our eyes. The field of vision that is perceptible to a machine's eyes is broader than that. Let us operate a robot with the field of vision of a machine. This would allow FANUC to realize a world in which the robot can be moved based on how the machine's eyes see.. I would like you to make further progress with sensing and perform optimal control after reliably collecting information from the real, physical world, to develop more functions than ever. This could be the basic concept of not only FANUC ROBOTs but all FANUC products. I look forward to your further growth.

That is all from me.

President Yamaguchi: Thank you, Professor Ishikawa. General Manager Inaba, please comment on what Professor Sakuma and Professor Ishikawa talked about.

K. Inaba: Thank you for your comments, Professor Sakuma, Professor Ishikawa. Your views on the collaborative robot, sensing, and simulation were very interesting. Although we focused on ease of use at this Open House, I will narrow down what I would like to say to ease of teaching because it is closely related to these three technologies. Professor Ishikawa referred to visual feedback as being a large step forward. We achieved the first step to have the robot follow and work on an object moving relative to the robot through control using vision sensor data. In addition, the shape capturing path generation package used in QSSR also utilizes vision sensor data. The real-world information captured through vision sensors is reflected in simulations to integrate the real world and the simulation as Professor Sakuma said. After this, operation commands generated in the simulation are returned to the real world. If I may quote Professor Higuchi, we are enabling "the interaction between the real world and the simulation world" bit by bit.


K. Inaba

I have realized that through these digital technologies, robots are shifting from the stage of repetitive operations in an environment predetermined to some extent, to a stage where they generate commands according to the situation they sense. On the other hand, we must resolve the issue of calculation resources that Professor Shirase pointed out, to make possible high-speed visual feedback, many types of sensor data processing, and other processing that Professor Ishikawa mentioned in the sensing area. This issue also applies to high-speed automatic path generation. In addition, we must take into consideration quantization errors, numerical calculation errors, and other matters that Professor Takagi pointed out in addition to physical model errors during simulation for advanced applications. Improvement of calculation efficiency is certainly an important future challenge.
Lastly, we emphasized ease of use including applications that take collaboration with people into account, at this Open House. We will continue to develop products based on reliability. We will especially endeavor to ensure reliability, while accelerating development to quickly address changing needs. We also plan to further enhance robotic functions in remote maintenance tools such as ZDT and FabriQR Contact. We want to develop robots that combine ease of use and reliability that everyone can easily use, and would like to request your guidance.

President Yamaguchi: Thank you. This completes the part focused on robots.

ROBOMACHINE

President Yamaguchi: Now, let's move on to Robomachines. First, we would like to hear from Professor Matsumura.

Professor Matsumura: Thank you for the introduction. I am Matsumura from Tokyo Denki University. Thank you very much for inviting me to the online round-table talk today. Because many professors have already spoken much about Digital Twin, FA, and general matters, I would like to mainly comment on the Robodrill.


Professor Matsumura

First, the development of the tapping spindle in the Robodrill caught my attention. This tapping spindle has a function that accelerates the rotation speed more than the standard spindle, and another function to lower inertia to shorten the acceleration time. I think FANUC developed this technology to meet users' needs for reducing the cycle time. Looking at the spindle, this particular Robodrill seems to have specifications for the middle range, and many users will get the impression that this model is easy to use compared to other models of this series. Thus, applying this to machining small-to-medium sized parts, especially automobile parts, can be expected more than before. At the same time, FANUC also provides high-speed specifications with a maximum spindle speed of 24,000 min2. Because the maximum spindle speed of the tapping spindle is half of that, users who use small-diameter tools for fine machining and other machining will probably select the high-speed spindle specification machines. Although the main theme is spindle development this year, I would like you to develop high precision and high acceleration table feeding in the future.
Another development theme is reduction in machining time. How to shorten the cycle time was exhibited. What is really interesting is that multiple operations that can be executed simultaneously can now be performed with a single command. I heard that combined operations were actually already possible in the past but was not known to many users. This means that by being able to exchange tools and perform positioning at the same time with a single command, the machining time is shortened. I am sure that this is one of the functions appreciated on site because it reduces the total time for parts machining for mass production. I admire you for such innovations as I imagine that modest though steadfast efforts were required.
I was also impressed with the automation of clamping and unclamping of DDR. I found it refreshing as I watched the video, and thought it was certainly different. I expect further research

and development will be conducted to reduce non-machining time as much as possible, including acceleration/deceleration of the table, although the development of control commands is already quite advanced.
I listened to the explanation about iHMI and support for networking beforehand, and actually saw them. It became even easier to include vendors' resources, and users can now easily connect via multifunctional Ethernet. I think this will lead to the use of IoT and further on to the implementation of AI. I have heard that small-to-medium-sized enterprises have a particularly hard time connecting to networks. This development seems to have taken their hardships into consideration.
LINKi seems to currently be at the stage of monitoring the status of multiple machines. If FANUC analyzes the decisions made by users in response to monitored information, and can make proposals based on the results in the future, users will probably want to incorporate this function.
This is a bit outside my field, but I also saw three options to connect a robot with QSSR. "QSSR ON-SITE" is a function to connect a robot to an existing machine. Users who have difficulty connecting a robot and do not know what to do would really appreciate this function. I found "QSSR AUTO PATH" to be very ambitious but I heard it does not support connection with the Robodrill yet. I wonder how long it takes to set up a robot to be operational using this function. If the required time is similar to "QSSR G-CODE," everyone would select the QSSR AUTO PATH option if they have the budget for implementation.
Regarding FA, I saw thermal displacement compensation using AI. The thermal displacement of machine tools is said to be a never-ending challenge. Other companies are also trying to achieve thermal displacement compensation in many different ways. In addition to thermal displacement compensation, I have high hopes for how FANUC will develop monitoring and recognition of workpieces, as well as operations in response to monitoring and recognition in the future. I particularly look forward to improvements in chatter vibration, machining errors, and finishing roughness.
AI servo tuning is also a very convenient function for workers on site. Automatic adjustment of servo settings for high-quality machining through machine learning is particularly groundbreaking. Although experience and knowledge are required to adjust servo parameters at a machining site, only a small number of workers have such experience and knowledge. So, this function is quite useful.
Overall, I think that FANUC has taken their concept of "easy to use for the purpose of providing machine tools and encouraging their use" one step further and started to help users make full use of their machine tools. As I said earlier, combined operations in which the machine table moves while exchanging tools with a single command is a good example. This idea is hard to come up with unless you observe seasoned workers carrying out their tasks on site. In fact, whereas beginners sequentially perform operations one by one, seasoned workers think about the next operation while executing their current one. This means that they often perform combined operations. In this sense, the function to perform combined operations with a single command is making it "easy to make full use of equipment" rather than just making the "equipment easy to use."
Regarding the hot-topic "Digital Twin," your technical development of the interface was impressive. You must consider not only hardware but also how the machine tool will adapt to machining phenomena as the first step to make full use of the machine tool. To do this, linkage with FA is probably required as well. I hope that the linkage with FA will be even more specific with the technologies you have developed.
At the same time, users are also concerned about the life time of machines and their components. I heard that FANUC is also conducting lifetime tests. When it comes to a sophisticated machine, the user is very interested in its lifetime, failures, recovery in case of failure, and maintenance. The user considers these aspects before installing a machine. Therefore, manufacturers should examine how to provide information and support.
In addition, to operate facilities for mass production such as powertrain production at automobile manufacturers, chip disposal often becomes an issue in controlling the cutting process. This is not about ejecting chips from chip breakers behind the cutting edge. It is related to a secondary process to dispose of chips accumulated on the table and surroundings. I have been asked for advice by several very distressed companies that want to know how to control the position or direction of chips that remain, or whether they should break the chips, since the accumulated chips hinder the table from rotating. It might be time for machine tool builders to figure out how to dispose of these chips from the standpoint of experts on site who have good knowledge and experience. Your products will be more attractive if you use your ingenuity in designing the machining space of the machines.
Developers who work for manufacturers have also probably heard users' opinions, or cries for help, as the case may be. In particular, FANUC is more advantageous in being able to provide support for controls and using them in machine tools than any other company, as a leader in this field. I look forward to your further development.
Let me thank you again for inviting me today.

President Yamaguchi: Thank you, Professor Matsumura. General Manager Tong from the Robodrill Research & Development Division will answer your questions.

Tong: Thank you for your comments on a wide range of topics, Professor Matsumura. Regarding the tapping spindle and reduction in cycle time, while this is not a good excuse, we have focused on the development of the machining capabilities and quality of machined surfaces in the past. However, recently we have decided to focus on light cutting applications of automobile parts and other parts for which the cycle time is important. I believe that what we have developed will help customers improve productivity and reduce costs, which will increase customer satisfaction.

Tong

Regarding the ease of use of machines that Professor Matsumura mentioned, I agree that we have moved from the stage where customers start using our products to the stage where they make full use of our products. We will continue to value users' opinions and help more customers easily make full use of the Robodrill in the future. This will also lead to customer satisfaction.

Finally, the chips that Professor Matsumura mentioned can be said to be a never-ending challenge for machine tools. What you said earlier gave us an idea. The direction in which chips are scattered or other factors can be controlled to some extent for certain machining methods. We will certainly consider controlling chip accumulation as well in the future.

Thank you.

President Yamaguchi: Now, Professor Kunieda, please let us hear your comments.

Professor Kunieda: I am Kunieda from the University of Tokyo. The Open House was really informative.

Professor Kunieda

I mainly saw the Robocut and found it phenomenal as the pitch precision and circularity have already achieved the order of one micron. Such precision is not achievable unless you mastered the basics from various points of view, including thermal displacement compensation through machine learning and structure analysis.

I have a question about this matter. I heard the explanation that FANUC increased rigidity and reduced thermal deformation through topology optimization, and as a result, the weight increased by 400 kg and 500 kg. I want to know why you ended up increasing the weight even though topology optimization usually leads to weight reduction.

I also have a request. Adaptive control has been taken for granted for electrical discharge machining since its invention. Adaptive control using gap voltage waveform or discharge current waveform is pretty common. The current signal processing speed allows us to apply adaptive control while observing each waveform of electrical discharge. However, each waveform is not associated with a phenomenon. In other words, it is not known what physical phenomenon of the actual electrical discharge resulted in that waveform. If you clarify this relationship through basic research using visualization or other methods, adaptive control using current and voltage waveforms will offer even better performance.

One more thing. The tool used for wire-cut electrical discharge machining is a very soft pliable wire. This is one of the factors that inhibit precision improvement. However, if you can measure the vibration, displacement, and deformation of the wire electrode with sensors, you can obtain various information from the behavior of the wire. One example is information on the discharge reaction force. The discharge reaction force from an electrical discharge vibrates or deforms the wire. The discharge reaction force changes, depending on the location or board thickness. If you can use the wire itself as a sensor by measuring the behavior of the wire in the process and by combining it with an inverse problem solution, you can provide adaptive control that is not possible just with current and voltage waveforms.

In addition, the detection of the position of electrical discharge, or where electrical discharge occurs has not been put to practical use for a long time. However, as overseas manufacturers have already included this function in machine tools, the trend to use the position of electrical discharge for many different purposes is becoming evident. I ask you to consider this as well.

In addition, the wire's behavior is very loose. It is similar to using the enveloping surface of a caterpillar that vibrates and deforms, for machining. The posture and form of the caterpillar changes as the diameter changes. If this can be simulated, precision will increase. Although this would require much tedious and steady basic research, I would like to ask that you make progress in this direction.

Lastly, there does not seem to be much theoretical research on dielectric fluids. Water and oil obviously lead to different machining results. However, the reason for this has not been found. Although an additive may be added as an intermediate dielectric fluid in some cases based on experience, machining characteristics completely change even with the same water if the conductivity is changed. The reason for this has not been clarified yet either. By finding the reason based on physics, I believe it would be possible to develop a dielectric fluid.

That is all from me. Thank you.

President Yamaguchi: Thank you, Professor Kunieda. Now, we would like to hear from General Manager Fujimoto, who supervises the research and development of the Robocut.

Fujimoto: Professor Kunieda, thank you for always supporting us in various ways with regard to clarifying electrical discharge phenomena.

First, I would like to answer your question about why the weight increased as a result of topology optimization, which addresses a similar question from Professor Hideki Aoyama earlier in the FA section. We needed a very thick machine with a solid structure for this new model to reduce thermal displacement and increase machining precision compared with previous models. Therefore, we could not avoid significantly increasing the weight. Given these circumstances, we used topology optimization to select which cast parts should be left thick to maintain its effectiveness. Although topology optimization is normally often used for weight reduction, we used it to ensure sufficient thickness to attain enough strength and increase rigidity and thermal stability. As a result, we were able to limit the weight increase to 400 kg in the smaller model and 500 kg in the larger model.

Fujimoto

In addition, as Professor Aoyama said, topology optimization may give way to a form that is difficult to manufacture by casting. We used topology optimization to identify where sufficient thickness should be retained rather than to reduce the weight to the minimum. In this sense, casting design was relatively easy.

I would also like to express my appreciation for the continuous support of Professor Kunieda for the simulation of wire behavior. We must investigate many different aspects of the electrical discharge phenomena in addition to the force applied to the wire, especially for the simulation of the wire behavior that we are currently conducting. As for the effects of dielectric fluid that Professor Kunieda mentioned earlier, we have not sufficiently understood them yet. So, we would like to steadily conduct basic research while asking for your advice. We appreciate your continuous help.

President: Thank you. Now, Professor Shamoto, please share your comments.

Professor Shamoto: I am Shamoto from Nagoya University. Thank you for inviting me to this round-table talk again. Because this is an online talk, I prepared slides thinking that sharing materials would be easier to understand.

Professor Shamoto

First, I am going to make some comments on the Robonano, which was assigned to me. The first topic is precise control of hydraulic pressure. As this graph shows, this technology precisely controls the hydraulic pressure for the hydrostatic guide to suppress fluctuation. This is a great technological development even if it seems bland at a glance. Ultra-precision is achieved as a result of accumulating and combining many different technologies, such as those for suppressing fluctuation in peripheral equipment and the environment, and requires much perseverance. It is great that FANUC succeeded in highly stabilizing such fluctuations in peripheral equipment, which was left to peripheral equipment manufacturers in the past, with servo technology, which is your area of expertise. We have no choice but to cumulatively improve these peripheral technologies one by one to refine the precision. I hope that FANUC will continue such development of peripheral equipment as well as the Robonano, including the oil pressure and temperature, ambient temperature, the pressure and temperature of compressed air, and coolant, in the future.

The second thing that caught my attention is the Smart M-Form technology. This is a contact-type on-machine measurement device that measures the machined surface to compensate form errors. Although the technology itself is not especially new, there is value in integrating it with an NC. In particular, the time required for ultra-precision machining and fine processing is long, and other processes such as measurement and setup tend to be time consuming as well. Therefore, it is critical to improve their efficiency.

I also would like to talk about the development of Smart M-Setup which allows operation of many different on-machine measurement units for Robonano. This is also great in that it contributes to reducing labor for setup. However, I understand that Smart M-Setup is still at a stage in which conventional on-machine measurement devices use conventional methods. So, this cannot be said to be a major advancement. I hope that FANUC will further pursue technological developments in this direction in the future. Recently, it seems that research and development have not advanced much in the field of setup, even though setup is important. We will also continue research, and would appreciate your advice.

Next, let me talk about the Robodrill. This slide shows a demonstration of machining steel using a spindle with a high torque. The trend of machining steel with a compact machine like this is on the rise. In the past, compact machines were mainly used for machining aluminum, but recently I have personally seen such compact machines used for machining steel in multiple companies. These companies all face the problem of chatter, though this is only natural. Chatter seems to increase when a compact machine with low rigidity is aggressively used to machine steel. Chatter has long been an issue for all machine tools. I believe that there are still other ways to eliminate chatter using NCs such as the technique of adjusting the spindle speed or identifying appropriate parameters. I hope that FANUC will continue to make advancements in such technologies.

That is all from me. Thank you.

President Yamaguchi: Thank you, Professor Shamoto. Next, Professor Omori, please tell us what you thought.

Professor Omori: Thank you for inviting me to this year's online Open House and round-table talk. I saw the Open House and technical documents and would like to comment on matters related to the Robonano.


Professor Omori

First, I am really glad to hear that you have announced the turning type Robonano. Many of the companies I work with are lens manufacturers that produce lens molds and use turning type machines frequently. I often used to hear that they were wondering when a turning type Robonano would be released. I heard that you will be launching a 0.1-nano turning type Robonano now and look forward to seeing just how high its precision actually is.
By the way, although the photos of the 5-axis type Robonano and the turning type Robonano were posted side by side, I wondered why the 5-axis type Robonano has the screen on the right whereas the turning type Robonano has the screen on the left. So, I looked at all the ultra-precision lathes in the laboratory and found that they all have the spindle and screen on the left. This is probably because setup is assumed to be performed with the right hand. When I visit customers' factories, however, surprisingly the screen is placed on the right even with an ultra-precision lathe, and is separated from the machine at some factories. In light of this, you may want to consider a model which can be separated with the screen on the right upon customers' requests. I recommend asking customers for their opinions and taking these into consideration before launching the turning type Robonano in the future.
"High machining performance," "minimizing downtime," and "ease of use" are common keywords for Robomachines. Looking at the "ease of use" exhibit, "AI" and "machine learning" were written above it. Actually, I started research and conducted analyses on the effects of machine learning during machining, and its performance and machining phenomenon a few years ago. Specifically, I am researching machine learning for grinding. I received requests from many different companies that want to automatically determine when the sharpness of the grinding wheel will change or when it has changed. I am carrying out this research to help solve this problem. The first issue is the machining load. As a grinder is a rotary tool, the quick way is to monitor the load, power consumption, and torque of the spindle to know the status. Another way is to monitor vibration during machining. I noticed that machining status can clearly be understood just with these two input values. Furthermore, more detailed phenomena information can be acquired by dividing the grinding resistance into a normal component force and a tangential component force and analyzing these features. Cutting marks, that is, how they appear on machined surfaces, is a problem especially in turning type models. Since quite a high level of quality is required, knowledge of the machining phenomena will become more important. I also believe machine learning will be important for the Robonano to make full use of 0.1-nano command values.
Professor Shamoto also mentioned on-machine measurement devices earlier. I have also studied on-machine measurement for a long time. According to the documentation, the measurement resolution is 0.1 nm and the Robonano also uses 0.1 nm command. In the era of 0.1 nm machining and control, measurement requires higher resolution such as one order of magnitude higher. Although Professor Kuriyagawa may comment on this later, this is the area of pico processing or pico technology. You should think about the maximum level of measurement resolution that will be required, along with the extent you will pursue the machining precision of the Robonano in the future, though you may find you are stepping into the quantum realm. In fact, companies to which I give advice are now asking for machining precision for lens molds that is one order of magnitude higher than the level we discussed just a few years ago. Now that we are actually in that era, I have high expectations for the future of the Robonano including the purposes for which measurement resolution and machining resolution will be pursued. I think this will introduce research themes and practical technological opportunities.
Lastly, you can start compensated machining without removing or attaching a workpiece during on-machine measurement. This is a great benefit. On the other hand, the reality is that many customers use data measured by external dedicated metrology systems for compensated machining. In such cases, workpieces need to be accurately removed and attached, but what is more, additional support may be required to transmit data measured externally to the Robonano, such as the data transfer method or communication protocol. This will depend on the customer. I recommend that you consider compatibility with external measurements as part of future usability.
That is all from me. Thank you.

President Yamaguchi: Thank you, Professor Omori. Now, we would like to hear from General Manager Hong from the Robonano Research & Development Division about the advice from Professor Shamoto and Professor Omori.

Hong: I am Hong. Thank you for your advice and comments on a wide range of topics.
First, we should have worked on the servo control of hydraulic pressure exhibited this year that Professor Shamoto mentioned, from the beginning. As Professor Shamoto said, the accumula-

tion of each factor, including how to control peripheral equipment and how to suppress disturbances, will lead to errors during ultra-precision machining. We developed the servo control after truly realizing that we cannot advance to the next step without working on servo control. Professor Shamoto has asked us about the range of applications and the extent of effectiveness of these applications. Among recent experiments, the best example to answer this question is diffraction grating. When several hundred thousand grooves were machined over dozens of hours, there was movement of slightly less than 30 nanos if the temperature changed by about 0.1°. This movement appeared as one line in the diffraction grating. This line no longer appears because robustness increased as a result of servo control.

Hong

As for the targets related to the Robonano, we are looking into disturbance suppression as mentioned, stabilization through peripheral equipment control, and ease of use, and are now focusing on on-machine measurement and the setup facilitation function.
As Professor Shamoto and Professor Omori commented on on-machine measurement, this is critical to the automation of ultra-precision machining and measurement. However, 0.01-nano measurement is required as Professor Omori said. This is the golden rule of ultra-precision machining and machining measurement in the true sense, and we would like to set it as a future challenge. We have also strongly felt the demand for compatibility with external measurements at recent business meetings and we appreciate your very practical advice.
As for the position of the operation screen that Professor Omori pointed out, the members of the Robonano Research & Development Division thought long and hard about whether we should attach an integrated screen on the left of the machine or provide a separate screen. We made a decision after internally considering many different aspects, but we have not fully verified it from a users' standpoint. We will consider the separate console that Professor Omori suggested and other options, listening to users' opinions in the future.
Professor Shamoto and Professor Omori have always advised us. We would like you to help us solve small problems in ultra-precision machining one by one to further increase precision in machining and provide ease of use.
That is all from me.

President Yamaguchi: Thank you. Professor Kuriyagawa, please share your comments.

Professor Kuriyagawa: I am Kuriyagawa from Tohoku University. I moved back to the Graduate School of Engineering which was my former work place, from the Graduate School of Biomedical Engineering last April. Now, I work for the Division of Mechanical Engineering in the Graduate School of Engineering. Thank you for inviting me to this round-table talk. I obtained very valuable information at the online Open House. Swipe Video was used for the presentations, and this was the first time for me to use it. I found it to be very simple and effective. I am really grateful.


Professor Kuriyagawa

As for the Robonano, I was also interested in the contact-type on-machine measurement device as Professor Omori also mentioned earlier. Although this device can of course quickly measure the cross-section surface, the whole surface needs to be measured in many cases in reality, because non-axisymmetric error patterns may appear on the axisymmetric aspherical optical lens. Development of a noncontact-type measurement method is required to measure the whole surface at maximum speed. I have developed a method for the 1 nm level, but 0.1 nm is quite difficult, as expected. So, I have high hopes for FANUC's development capabilities.
I specialize in grinding like Professor Omori. I started studying grinding in the 1980s with creep feed grinding for jet engine turbine blades. The purpose was high-efficiency machining to mass-produce parts made of a material difficult to grind. Then, I did research on ultra-precision grinding, nano precision, and pico precision machining that Professor Omori mentioned earlier, since the 1990s for high precision and high quality machining. Although the evolution and development of hardware has been vital to my research, I have recently become aware just how critical software development is if one is to make full use of the hardware.
Professor Asama talked about Digital Triplet that is to follow Digital Twin. I would like FANUC to complete and realize the optimal placement of machine tools, the safety of workers, comfort, and even the achievement of a feeling of happiness that Professor Asama mentioned.
On the other hand, we must definitely solve issues related to recycling and reuse, to use old products as resources in addition to production and full utilization of products. That is why I really hope that FANUC will propose a direction for recycling-style manufacturing.
About nano precision and pico precision, I think form creation machining will not be sufficient in the future. In other words, we will need to add functionality to the product surface or the crystal structure below the surface. It will be important to create higher-value added products through this process. For example, the surface structure can now be easily controlled through machining. I would really appreciate it if you conducted development bearing new technologies in mind. These technol-

ogies include control of internal crystal structure, control of vacancy in the material to change the mechanical characteristics of the whole material, giving direction to the characteristics change, and the technology needed to create multi-material structures that contain many different materials.
As for customers who buy these products, a product that provides machining with nano precision or pico precision can be used to some extent in the semiconductor field. For example, I am sure that machining is useful for the interlayer dielectric films in recently developed stacked ICs with 100 or 200 layers. I have the feeling that machining with such precision has plenty of potential to be applied in such a field.
Let me thank you again for inviting me today. This is all from me.

President Yamaguchi: Thank you, Professor Kuriyagawa. Now, General Manager Uchida, do you have anything to add?

Uchida: I am Uchida. Thank you very much for your valuable opinions from various angles. I would like to comment on Digital Twin, which was the most talked about subject today, including Robomachine. Although General Manager Noda has already described our current efforts, I would like to take a step further and explain our future direction.


Uchida

Although one of the catchphrases for this year's online Open House is "Digital Twin with FANUC CNC," we were asked by Chairman Inaba in advance to change this to "Digital Twin by FANUC." So, we plan to use the unified concept, "Digital, Real & Connecting" for FANUC as a whole next year, apart from whether Digital Twin is a suitable term.
"Digital and real" or "cyber and physical" are often used these days. But, a young general manager in our CNC-related department said, "It would be better to add 'connecting' as well." This makes sense. Conducting simulation and actual machining and measurement without linking them is almost meaningless. It is important to share data and information as needed between them. As a result, we decided to include the concept of "connecting" in the end, and adopted "Digital, Real & Connecting" as the concept that shows the direction of FANUC. This is something like "Dynamic Digital Twin" if I were to borrow the word "dynamic" from Professor Shinno. However, many of you seem to be unsatisfied with the term "Digital Twin." We will try to find better wording in the future.
If someone were to ask me what the core of FANUC's Digital Twin is, I would have to say that it is servo technology. When our CNC competitors use the word, "Digital Twin," most systems only cover CAM and CNC and do not contain most of the subsequent servo system and actual machining, even though the term, "twin" is used. So, we would like to further strengthen the servo system for differentiation in FANUC's Digital Twin concept. Fortunately, FANUC has been providing a powerful tool named SERVO GUIDE to collect servo behavior for over twenty years now and has recently taken it a step further. We plan to include all information including CAD data, CNC simulation results, measurement results from the on-machine measurement devices, and measurement results from external measurement instruments in the SERVO GUIDE in the next-generation CNC. We want to create various kinds of added value by consolidating different kinds of machining data in SERVO GUIDE.
After hearing this, the professors who attended today will probably say, "That's fine for the servos, but what about the tools?" Unfortunately, FANUC is a heavy tool user, but it does not have a tool development department. I think this is one of our weak points. Therefore, we would like to complete FANUC's concept by receiving various insights from professors on tool-related simulation and capturing behavior to fill the gap in what FANUC is missing.
Thank you for attending this round-table talk today.

President Yamaguchi: Thank you.

Summary

President Yamaguchi: Finally, we would like to ask Professor Tojiro Aoyama to comment on the Open House as a whole. Professor, if you would.

Professor T. Aoyama: Thank you for inviting me to this round-table talk today. I also saw your online Open House. As Professor Higuchi said at the beginning, I was able to understand the flow of this online Open House very well by first listening to the seminars and then seeing individual exhibits. Because the other professors also took time to see individual exhibits including seminars


Professor T. Aoyama

in advance, today we were able to have numerous discussions, perhaps more varied than President Yamaguchi expected. However, we were not able to feel the impact of high load cutting, the vibrations, the sounds, get a sense of scale in three dimension, and other aspects of the Robodrill that we could experience by being on site. Therefore, I suggest that you figure out a good way to combine them.
I was particularly interested in the Robonano and collaborative robot. The "green robot" exhibited two years ago has gradually evolved. By seeing this year's exhibits, I got the impression that the development of the collaborative robot has advanced and

started in full swing. Hearing the other professors such as Professor Sugano talking about tomato harvesting, Professor Sakuma talking about the medical field, and the soft gripper, I think that FANUC will be able to target new customers in fields that you have not focused on so far, by combining your collaborative robot and these technologies. Professor Kuriyagawa said earlier that FANUC will have a wider range of customers and I also felt that the target market, or the breadth of targets, will expand further even if the main customers remain machine tool builders.
Although FANUC manufactures and provides products to society, I think that FANUC will put more focus on how society functions, how their products are accepted in society, and how collaboration between industry and university professors in academia link with society to contribute to new manufacturing in the future.
I saw face-to-face ACADEMY Training Courses in FANUC ACADEMY and eACADEMY online. FANUC also provides training online by combining on-demand and real-time live seminars. Universities suddenly started providing education online in the spring semester of 2020. Everyone in academia says that the old education style will not come back even after the COVID-19 pandemic subsides. I think universities are working on enhancing online and face-to-face real education, but each university has its own way of thinking about how to go about it. FANUC is already providing online training in full force. It would be wonderful if FANUC ACADEMY shared problems, requests from attendees, good points, and other information on online and face-to-face courses with the academic world, so that we can think about how to effectively structure hybrid education consisting of online and face-to-face classes to develop human resources. I am also very interested in training lecturers on online courses. Universities can learn a lot from FANUC ACADEMY.
In addition, I assume that FANUC, as a global company, will communicate its approach to carbon neutrality as needed through various media. I would like you to also exchange opinions on this matter with academia.
Thank you very much for organizing this online round-table talk today. Please allow me to thank Chairman Inaba, President Yamaguchi, and other FANUC members again on behalf of academia.
Various opinions and comments were presented from members of academia today. I hope that FANUC will find them informative and that FANUC and academia will develop together. I am looking forward to working with you in the future. Thank you everyone.

President Yamaguchi: Thank you for your warm comment, Professor Aoyama. Thank you everyone for taking time from your busy schedules to attend this long meeting. I also appreciate that you took the time to see the Open House before attending the round-table talk today. We are grateful for your valuable advice. You can view the online Open House for as long as you wish and see it repeatedly. These are advantages of holding an Open House online. However, we must admit the online Open House also has its disadvantages. To be precise, it is not interactive and visitors cannot ask questions. I hope that we will be able to hold a physical Open House next year, and also a round-table talk, inviting all the professors to one place, if possible. However, I think that some of you may not be able to come in person because of your schedule. In such a case, we will consider asking those professors to attend online. Thank you again for getting together today despite being very busy. We will adjourn the meeting.
Thank you.

Four Seasons of FANUC

Insects become more audible as the heat of summer wanes. The thick forest of FANUC is full of flowers and berries that add color to our short summer. This section introduces some small, yet beautiful flowers that modestly appear between the shadows of the deep green.

Kirengeshoma palmata

Adenophora triphylla

Vicia amoena

FANUC Factory Introduction

Manufacturing of Roboshot base frames

The base frames of the Roboshot, which directly affect the machine's precision, are manufactured in FANUC's Roboshot factory. Base frames are large parts, with a maximum length of 6 meters and weight of 2 tons. Base frames are manufactured in four major processes.
In the first process, tapping is performed on column parts. In the second process, columns after tapping and other parts are welded together. The top surface of the base frame is machined in the third process, and in the final fourth process, the base frame is painted. We have automated these processes using robots for high quality and high productivity.

In the column machining process, a robot detects steel material on the pallet with a vision sensor and loads it to a Robodrill.

In the welding process, two welding robots detect the position of the base frame with touch sensing to weld parts accurately. The base frame is mounted on the turnover device driven by the servo motor and the orientation of the base is freely changed to weld all surfaces.

In the top surface machining process, a super heavy payload robot with a payload of 2.3 tons checks the base frame taken out of the automated warehouse with its vision sensor, and sets it up on the machining jigs of a gantry milling machine. By changing the robot hand, jigs can be exchanged as necessary when the model is changed. As such, 24-hour continuous unmanned machining of base frames is possible.

In the painting process, two paint robots on rails detect the position of the base frame to achieve high-quality painting.

Each of the welding, machining, and painting processes are connected to a large automatic warehouse. The automatic warehouse is used as a transport device to reduce logistics work.
In addition, all robots and machine tools are connected to a network. FIELD system collects and analyzes information to improve productivity and quality.

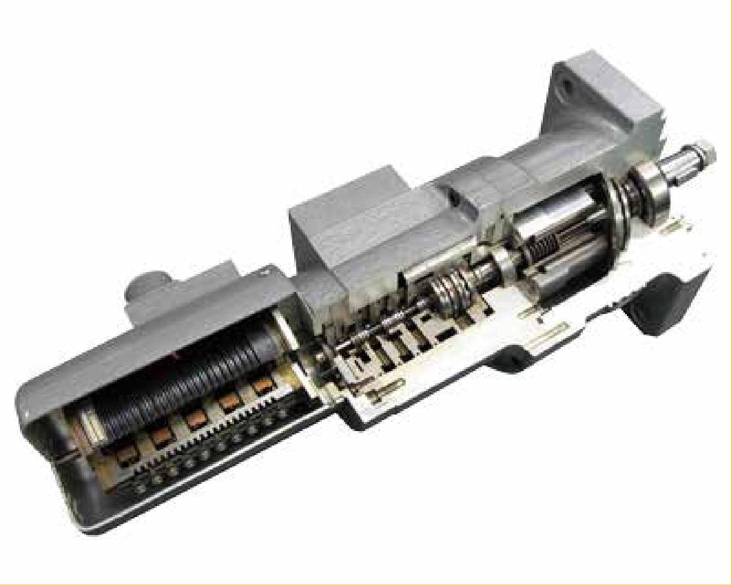
Robots are used to produce base frames to achieve the high precision and high quality of the Roboshot.

Column machining process
(The robot supplies column checked
with vision sensors to the ROBODRILL.)

Welding process
(Two robots weld the base
frame on the turnover device.)

Top surface machining process
(The super heavy payload robot sets the
base frame up on the machining jig.)

Painting process
(Two robots give the base
frame a high-quality paint job.)



FANUC's History Series 2
"Electric/Hydraulic Pressure Pulse Motor"
Developed and patented in 1959. This motor developed by FANUC's founder, Dr. Seiuemon Inaba, can be said to be the origin of FANUC.
With the unique built-in hydraulic pressure control mechanism, the hydraulic pressure motor with a large torque follows the movement of the input electric pulse motor. The motor enables stable high-precision operation with simple open loop control and was used for axis feeding in many machine tools.

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