Distance Learning and Technology Transfer with Reality Transmission Capability

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Abstract

This paper discusses a distance learning system with reality transmission capability. Actual experience is crucial for education, in that much knowledge is obtained through the comparison of predictions with experimental results. Reality transmission capability allows real experiments to be performed in a distance learning system. Requirements for such a system are: (1) reality transmission capability, (2) bidirectional information transmission capability, and (3) independence of time and location. Experimental results are presented using a cutting simulator composed of a user interface to determine the cutting conditions, a stability lobe diagram and a display of cutting force, auditory and tactile information. A micro-machining experience system and a remote manufacturing system using a real time tracking vision system as an advanced user interface are also presented. Furthermore, a technology transfer experiment using the networked manufacturing system with reality transmission capability is discussed.

Keywords: Distance Learning System, Technology Transfer, In-Process Monitoring

1 INTRODUCTION

Information engineering, telecommunications, medical services, welfare, life sciences and biology, including brain science and genetic engineering, are expected to be among the most productive technical areas in the 21st century. It is important to consider the impact of these emerging areas. With the advancement of the IT, it becomes possible not only to observe a machine and a system in a remote place, but also to operate them. It also becomes possible to operate a machine working in a special environment, such as at the atomic or molecular scale, in a vacuum or at high temperatures. Recent advancement of VR and simulation technology provides a means to enter a virtual world as if an operator were in it. In such an environment, it is possible to change parameters arbitrarily and to experience their effects. Actual learning is obtained by comparing the predictions of the operator with the actual results and by experiencing these phenomena. Furthermore, our brain is stimulated when new ideas can be experienced quickly and knowledge is confirmed with action.

2 RELATED WORK

Concerning open architecture machine tools, there are several projects such as OSACA, OMAC and JOP. The trend was reviewed in [1]. Wright, et al. have developed an Internet-based design and manufacturing system on an open-architecture machining center [2]. Houten, et al. have developed a network based virtual maintenance system for robust design, product monitoring, fault diagnosis and maintenance planning [3]. A business model to cope with rapid market change is discussed in [4].

Concerning key technologies for tele-operation, we have a good review of time delay problems [5]. In particular, Anderson, et al. proposed a strategy for bilateral control to maintain the stability of a system with time delay [6].

Concerning chatter vibration, the stability lobe phenomenon has been discussed [7] and its effects have been used to improve the metal removal rate in milling [8].

The importance of nano and micro manufacturing is well explained, for example, in [9], [10], [11] and [12].

3 NECESSITY OF EDUCATION WITH REAL EXPERIENCE

There are two ways for learning, deductive and inductive methods. Trials based on hypotheses are repeated and the predictions and the actual results are compared to acquire knowledge. Human error should be allowed for in a system for providing real experience because there is a possibility that a failure may occur during the learning process. It is also important that the trial can be made independent of time and location restrictions, which means at desired time and from a desired location of the learner. When we consider the environmental, food and atomic issues, learning and generation of knowledge should be executed at a global level. Furthermore, victory or defeat of a company is determined by the efficiency of technology and knowledge transfer while the enterprise is being globalized.

4 BASIC STRUCTURE OF THE SYSTEM

4.1 Forms of education and technology transfer system with reality transmission capability

The following forms can be considered to be education and technology transfer systems with reality transmission capability: (1) a bidirectional attendance system for a lecture, exercise and experiment at a fixed location, (2) a dispatch system for transmitting the lecture, exercise and experiment to multiple other locations, and (3) a system to enable the operation of a machine in a remote laboratory from the classroom. It is also possible to realize ‘an education by touching an actual object’ by using the system. Furthermore, by combining the distance learning system with a high speed simulator, it is possible for a student to enter into, for example, the atomic and molecular level world and to touch an object with the sensation of real feeling. The system provides an educational environment with real feeling in the areas of semiconductor fabrication, molecular dynamics, ultra precision manufacturing and thermo-fluid dynamics. Furthermore, a student can feel the vibration of an actual earthquake while learning the aseismatic structure of a building and evaluate the design by virtually existing in the space after the architectural design of the building is completed.

4.2 Components of the system

To learn about the emerging areas discussed at the beginning of the paper such as information engineering, telecommunications, medical services, welfare, life sciences and biology, including brain science and genetic engineering, the target areas are, for example, the nano/micro world and the human body. It is impossible for a human being to enter these environments. In this paper, the environment which people cannot go into is called a ‘hyper environment.’ The following three parts are necessary to realize a system which works in a hyper environment: (1) a machine which works in the hyper environment, (2) communication lines, and (3) a multi-media cockpit as an operator side system. It is necessary that the controller of the machine which works in the hyper environment accepts information in real time from the information network, such as a computer network, to operate the machine. Various kinds of sensors should be included to detect the phenomena which occur in the hyper environment. A hardware-type fail-safe mechanism is indispensable, so as not to destroy the machine due to the operator's mistake [13]. The communication lines should have the enough throughput to transmit the phenomena which occur in the hyper environment in real time to the operator. At the operator's site it is necessary to be able to present various kinds of information, such as visual, auditory, force, tactile and temperature information.

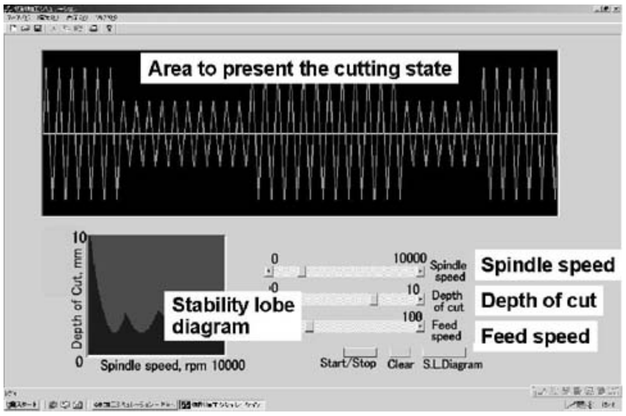


Figure 1: Panel for chatter vibration learning system.

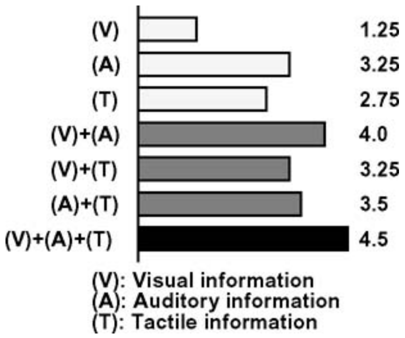


Figure 2: Experimental result using chatter vibration learning system.

5 CHATTER VIBRATION LEARNING SYSTEM

5.1 Construction of the system

The operator can input the cutting conditions, such as spindle speed, depth of cut and feed speed from the simulator panel as shown in Figure 1. The system judges whether the cutting state is a normal or chatter state depending on the input cutting conditions according to the previously obtained stability lobe diagram [14]. The judged result is presented as wave information. It is also presented as auditory and tactile information. The amplitude of the wave is small when the cutting state is normal, and is large when the chatter vibration occurs. For the auditory information presentation, low frequency sound with a long interval is presented when the cutting state is normal. High frequency sound with a short interval is presented when chatter vibration occurs. If the chatter vibration occurs, an eccentric weight at the grip of the joystick is rotated which causes the operator to sense vibration.

5.2 Experimental results with the chatter vibration learning system

In the experiment various kinds of information, such as visual, auditory and tactile information were presented separately and simultaneously. Subjects evaluated the system and scored from 5(high) to 1(low). Figure 2 shows the results. Auditory information was effective when each kind of information was presented separately. In addition, the operator was also able to accurately judge the cutting state when auditory information and visual information were transmitted simultaneously.

6 MICRO MACHINING EXPERIENCE SYSTEM

Nano and micro order manufacturing are crucial in the advanced technology areas discussed in this paper. Therefore, a micro machining and handling system which works in the vacuum chamber of the stereo type SEM(scanning electron microscope) was implemented as shown in Figure 3. A coil to change the direction of the electron beam is attached on the SEM. The direction of the electron beam is changed alternately from the left to the right direction in successive scans. On the observation monitor, the visual information from left and right direction is displayed in alternate frames. The operator can see the object stereographically using a liquid crystal type shutter which is synchronized with the frame rate. Then, the image is transmitted to the classroom and displayed on the screen. The frame change is detected and the synchronous signal is generated. The synchronous signal is sent to the liquid crystal shutter, which the operator is wearing, through the infrared transmitter located at the front part of the classroom.

Micro machining is realized by moving a cutting tool relative to a workpiece using a joystick. The information from the multi-axis force sensor which is installed in the system is fed back to the joystick after amplification and it is also converted into auditory information. When the chatter vibration is detected from the multi-axis force information as shown in Figure 4 by the method described in [15], an

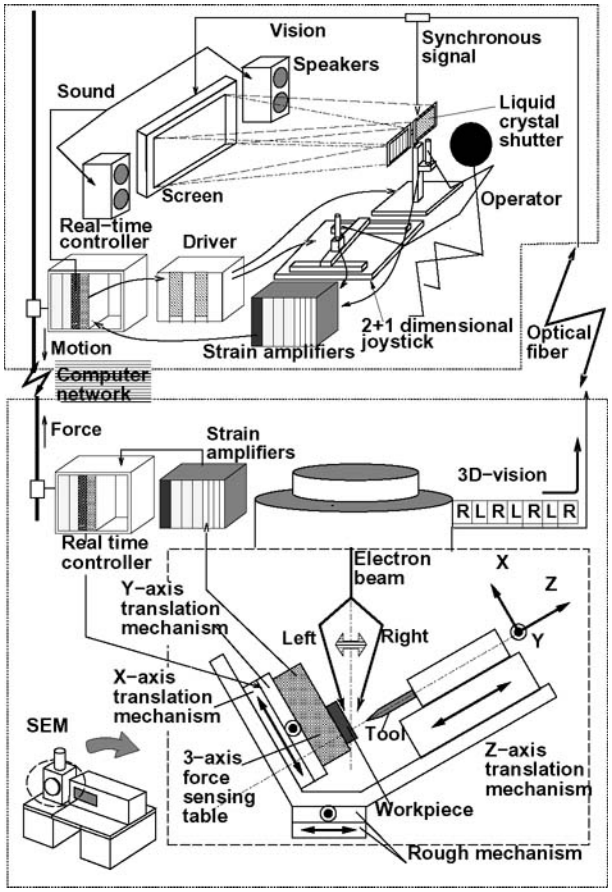
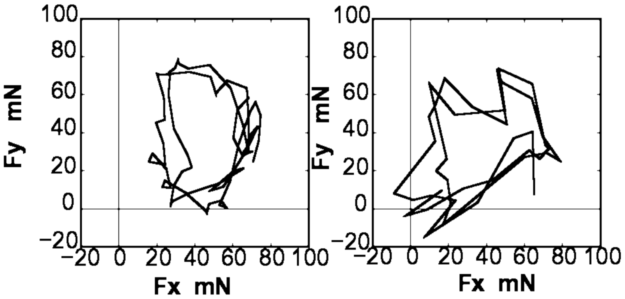


Figure 3: Micro machining experience system with stereo type SEM.



(a) Normal cutting **(b) Chatter cutting**

Figure 4: Force vector locus in micro cutting.

eccentric weight located at the grip of the joystick is rotated, presenting vibration information.

7 REMOTE MANUFACTURING SYSTEM WITH ‘ACTION MEDIA’

7.1 Overview of the system

It is possible to use a multi-axis joystick to set the cutting tool position and to reflect the cutting force and cutting state, such as the presence of chatter vibration [16]. However, to realize a distance learning system, it is rather difficult to implement a system which requires a special and sophisticated apparatus, such as a force feedback type master manipulator. It is possible to recognize the cutting state using visual and auditory information. Therefore, an input environment has been developed using a real time tracking vision system as an advanced user interface called ‘action media.’ To improve the accuracy of the commanded profiles, an input environment for the cutting of standard shapes, such as rectangles, circles and simple curves, was implemented. A remote operation and distance learning experiment was executed controlling the developed system through a satellite communication line, and the effectiveness of the system was evaluated.

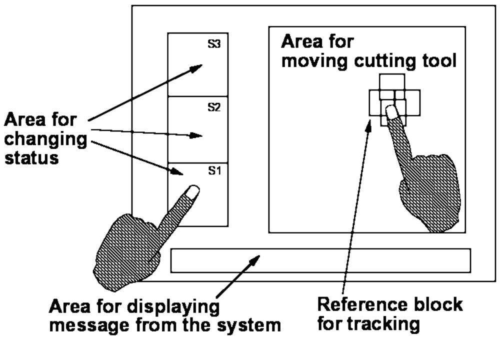


Figure 5: Operational environment with ‘action media.’

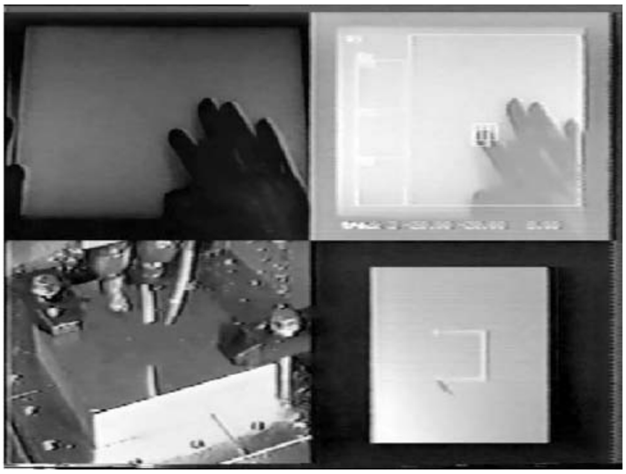


Figure 6: Operational environment for the operator while inputting rectangular shape.

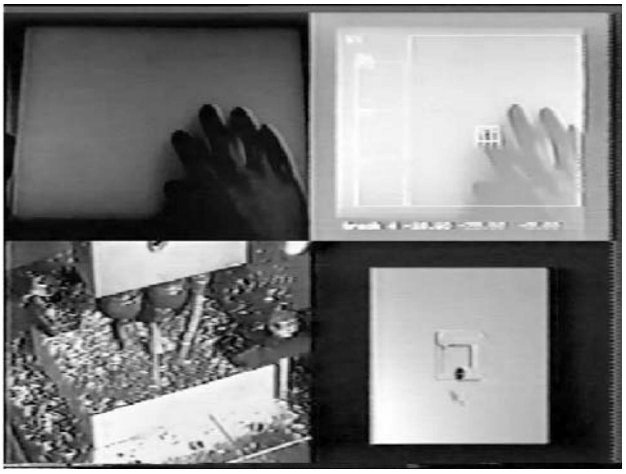


Figure 7: Operational environment for the operator during cutting.

7.2 System construction

The motion of the operator’s finger is obtained by the TV camera in the operation room and the scene is sent to the machine site. The transmitted visual information is processed by the real-time tracking vision system to convert the visual information of the finger motion into position information. The position information is transmitted to the real-time controller of the machine tool and the motion of the machine tool is realized. The operator is able to monitor the cutting state and the geometrical relation between the

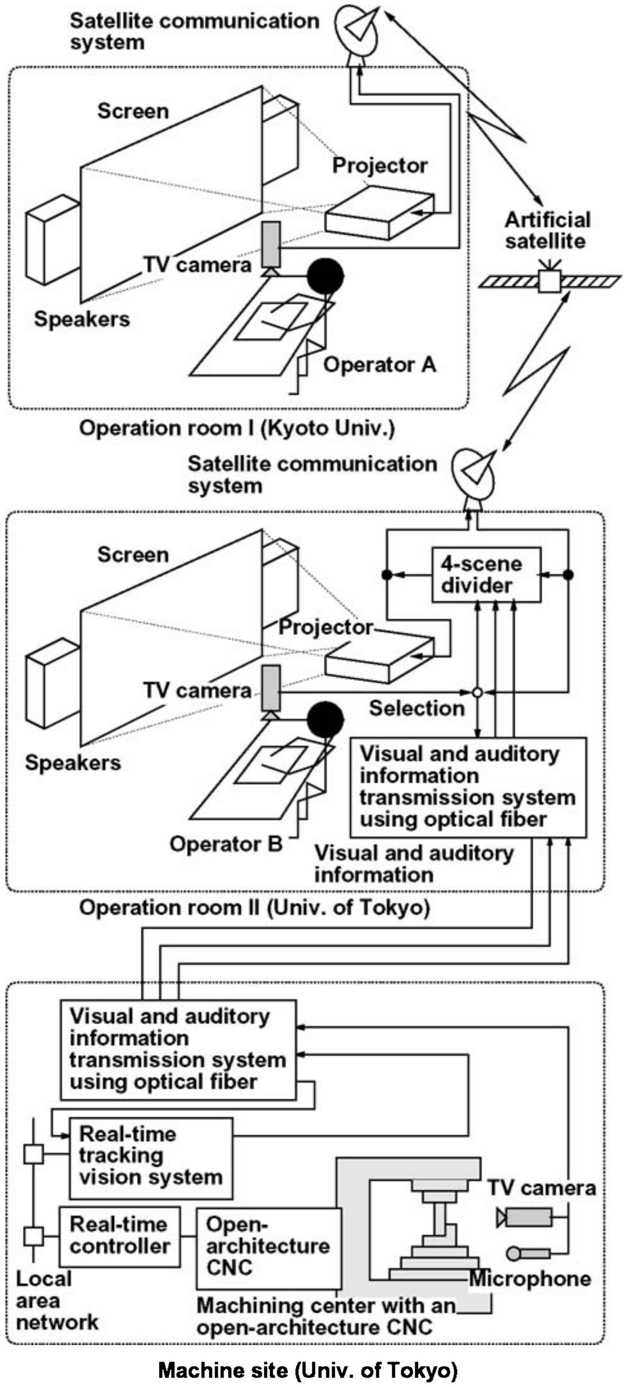


Figure 8: Remote machining system using ‘action media.’

cutting tool and a workpiece by using the visual and auditory information from the machine tool sent by the TV camera and the microphone. The machining center used in the experiment has an open-interface for an external real-time controller and has the capability of changing the spindle speed and feed speed, and for shifting the position of the cutting tool in real time.

7.3 Input environment with real-time visual tracking

The visual information processing system displays the visual information for the user interface overlaid on the visual information of the hand motion of the operator (Figure 5). The overlaid visual information is returned to the operator. The operator controls the system by moving his/her hands based on the returned operational environment (Figure 6). The operation is executed using the operator's finger and the input mode for the right finger can be switched using the left finger (Figure 5). For example, the system has motion modes in both the Z-direction and in XY-plane. While cutting in the XY-plane, the depth of cut is constrained as constant. In this mode, the XY position of the tool is set by the right finger.

7.4 Shape cutting function

Overview of the shape cutting function

During prototype manufacturing, it is important to machine a mechanical part from stock, even if its shape is not precisely determined. To support this requirement, it is insufficient to cut a mechanical part only by tracking the operator's finger position. Therefore, an input method for determination of the desired shape and a corresponding function for tool path generation have been implemented. It is also possible to modify the preliminary machined shape using these functions.

Implementation of the shape cutting function

The processes from shape determination to machining are as follows: (1) The operator determines the shape of the workpiece (Figure 6). (2) The motion of the tool is constrained based on the determined shape information and the input position information. (3) The determined shape, tool position and the input position information are displayed. (4) Actual cutting is executed (Figure 7). Visual information is created by the computer graphics and is down converted for display on the TV monitor in the operation room. To input the shape information for cutting, a series of vertices for a figure is determined sequentially. To determine the vertex position, at first the operator fixes the right finger and then the left finger is moved into the determined section. After the completion of the vertex position input, the tool position relative to the workpiece is determined in real-time based on the finger position of the operator and the preliminary input figure information. The position of the cutting tool is controlled by an NC controller. Therefore, the cutting accuracy of the boundary is the same as that of a conventional machine tool. The tool position of the machining center is determined as follows: [Process 1]: Lattice points near the current tool position are selected as candidates for the next tool position. [Process 2]: Interference with the shape cutting boundary for each candidate position is checked. If an interference exists, the candidate position is modified as a point on the boundary. [Process 3]: When the current tool position is located on the boundary or on a vertex, candidates for next position are also set on the boundary. [Process 4]: Among the candidates for the next tool position, the closest position from the input position obtained by the tracking of the finger is selected as the next tool position. Adopting the method described above, the required amount of data is almost constant, independent of the complexity of the shape being cut. Furthermore, the system has the flexibility to modify the unit length in [Process 1] and to change the shape of the cut. To change the shape of a curved boundary, the boundary is represented as a B-SPLINE curve and is divided into a set of straight lines. The calculation time to select the next tool position depends on the number of boundary lines selected. The necessary calculation time increases proportional to the number of lines and is typically less than 100 milliseconds.

7.5 Experimental setup

No.	Input of the shape (s)	Cutting (s)	Total (s)
1	88	223	311
2	89	251	340
3	136	143	279
4	123	188	311

Table 1: Required time for shape cutting.

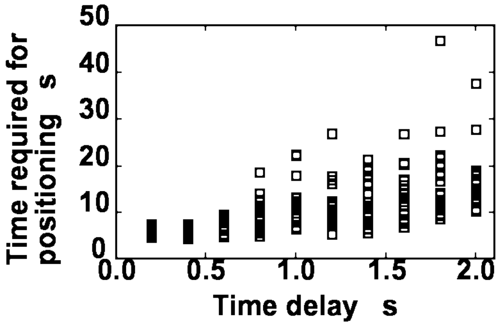


Figure 9: Relationship between time delay and the time required for positioning.

Inter-university distance learning system 'SCS'

The Ministry of Education in Japan established an inter-university distance learning system called SCS (Space Collaboration System) in 1995. In April in 2001, stations at 150 sites in 123 institutions, including major national universities, private universities, colleges and national institutes have been connected. The National Institute of Multimedia Education (NIME) operates the HUB station which controls the VSAT (Very Small Aperture Terminal) stations set up in universities, colleges, etc., and NIME manages the entire network and all of its channels through the operation of the HUB.

At the University of Tokyo, the VSAT equipment is located in a different building than the machine tools and nano/micro machining systems. They are connected with each other by ATM and direct optical fiber to establish the communication link with SCS. The network allows stereographic visual information to be simultaneously sent and received.

Remote operation training experiment

In the experiment, Kyoto University and the University of Tokyo were selected as operation room I and II, respectively. The machine site is located at the University of Tokyo as shown in Figure 8. A digital link called SCS, which is described above, with throughput of 1.5Mbps using an artificial satellite was adopted as a communication link to transmit visual and auditory information. In the experiment, operator B in operation room II showed the operation method to operator A located in operation room I. Then, operator A controlled the machining center using both fingers. The cutting operation was successfully executed in spite of a measured time delay between 0.31 and 0.36 seconds. However, the operator had to wait for a short time when he/she puts his/her finger in the rectangular area for the operation in Figure 5 because of the time delay.

7.6 Shape cutting experiment

Using the shape cutting function developed in this paper, it took only 5 to 7 minutes from design to cutting for a workpiece with a simple pocket. Table 1 shows the time required to input the shape information and cutting, respectively. Figure 9 shows the relation between the amount of time delay and the necessary time for positioning a finger. It was expected that the necessary time would increase proportional to the amount of the time delay. However, the primary result noted was that the operator-dependent variability of the required time increased rapidly as the time delay increased.

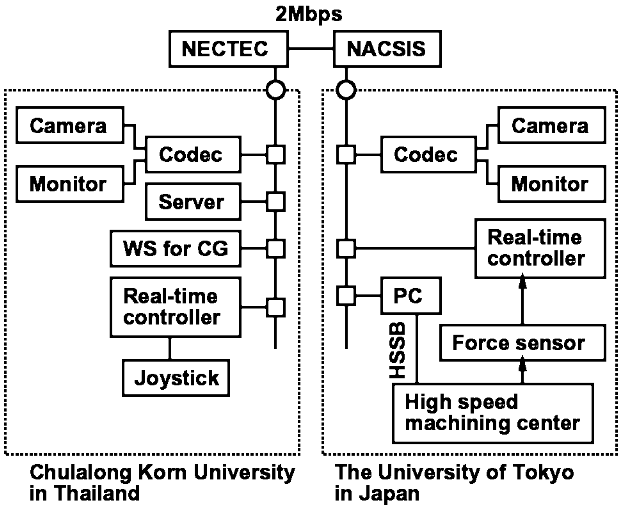


Figure 10: Technology transfer system with reality transmission capability for a south east Asian country.

8 TECHNOLOGY TRANSFER FOR A SOUTH EAST ASIAN COUNTRY

The University of Tokyo has a technology transfer agreement with Chulalong Korn University in Thailand. The authors have developed a system to be able to operate a high-speed machining center at the University of Tokyo from Chulalong Korn University, so that students there can learn the relationship between the cutting conditions and the results with real feeling as shown in Figure 10. The throughput of the communication link is approximately 700 kbps. The refresh speed of the visual information is once every 2-3 seconds, and the time delay of the visual information is approximately 3 second. Therefore, it was rather difficult to recognize the cutting state with the visual information which is directly sent to the operator in Thailand. In the developed system, however, the visual information was predictively displayed on the screen in front of the operator according to the motion of the joystick. Furthermore, if the chatter vibration was detected at the University of Tokyo, the information was transmitted to the operator and the high frequency vibration was presented using the mechanism as mentioned in the previous section. These functions increased the operability of the system by compensating the time delay.

9 CONCLUSIONS

This paper presented a distance learning and technology transfer system with reality transmission capability. The need for educational systems with real experience is discussed. Much knowledge is obtained through the comparison of predictions with experimental results. Reality transmission capability allows real experience to be obtained in a distance learning system. In the paper, the following examples are introduced: (1) Chatter vibration learning system, (2) Micro machining experience system with stereo type SEM, (3) Remote machining system with advanced user interface, and (4) Technology transfer system for a south east Asian country. Construction methods and the information transmission and presentation technologies were presented and the effectiveness of the developed system was confirmed through the experiments.

REFERENCES

[1] Pritschow,G., Altintas,Y., Jovane, F., Koren, Y., Mitsuishi, M., Takata, S., Brussel, H., Weck, M. and Yamazaki, K., 2001, Open Controller Architecture – Past, Present and Future, Annals of the CIRP, 50/2:463-470.

[2] Wang,F.C. and Wright,P.K., 1998, Internet-based Design and Manufacturing on an Open Architecture Machining Center, Proc. Japan-U.S.A. Symp. on Flexible Automation, 221-228.

[3] van Houten, F.J.A.M. and Kimura, F., 2000, The Virtual Maintenance System: A Computer-Based Support Tool for Robust Design, Product Diagnosis and Maintenance Planning, Annals of the CIRP, 49/1:91-94.

[4] Kjellberg, A., et al., 2000, Business Innovation – Innovative Teams, Competence Brokers and Beehive Structures – in a Sustainable Work Organization, Annals of the CIRP, 49/1:355-358.

[5] Sheridan,T.B., 1993, Space Teleoperation Through Time Delay: Review and Prognosis, IEEE Trans. Robotics and Automation, 9/5:592-606.

[6] Anderson, R.J., et al., 1990, Bilateral Control of Teleoperators with Time Delay, IEEE Trans. Automatic Control, 34/5:494-501.

[7] Tobias,S.A., 1964, Machine Tool Vibration, John Wiley & Sons, Inc., New York.

[8] Smith,S., et al., 1998, The Effect of Tool Length on Stable Metal Removal Rate in High Speed Milling, Annals of the CIRP, 47/1:307-310.

[9] van Brussel, H., Peirs, J., Reynaerts, D., Delchambre,A., Reinhart, G., Roth, N., Weck, M. and Zussmann, E., 2000, Assembly of Microsystems, Annals of the CIRP, 49/2:451-472.

[10] Masuzawa, T., 2000, State of the Art of Micromachining, Annals of the CIRP, 49/2:473-488.

[11] Corbett, J., McKeown, P.A., Peggs, G.N. and Whatmore, R., 2000, Nanotechnology: International Developments and Emerging Products, Annals of the CIRP, 49/2:523-545.

[12] Geiger, M., Kleiner M., Eckstein, R., Tiesler, N. and Engel, U., 2001, Microforming, Annals of the CIRP, 50/2:445-462.

[13] Hatamura, Y., et al., 1990, Development of a fail-safe system for NC machining centers, Annals of the CIRP, 39/1:409-412.

[14] Mitsuishi, M., et al., 1996, A Practical Machining Condition Determination Strategy Using Multi-Axis Force Information, Annals of the CIRP, 45/1:373-376.

[15] Mitsuishi, M., et al., 1992, Real-time Machining State Detection Using Multi-axis Force Sensing, Annals of the CIRP, 41/1:505-508.

[16] Mitsuishi, M., et al., 1999, Networked manufacturing with reality sensation for technology transfer, Annals of the CIRP, 48/1:409-412.