Knowledge Acquisition and Job Training for Advanced Technical Skills Using Immersive Virtual Environment*

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Abstract
The environment in which Japanese industry has achieved great respect is changing tremendously due to the globalization of world economies, while Asian countries are undergoing economic and technical development as well as benefiting from the advances in information technology. For example, in the design of custom-made casting products, a designer who lacks knowledge of casting may not be able to produce a good design. In order to obtain a good design and manufacturing result, it is necessary to equip the designer and manufacturer with a support system related to casting design, or a so-called knowledge transfer and creation system. This paper proposes a new virtual reality based knowledge acquisition and job training system for casting design, which is composed of the explicit and tacit knowledge transfer systems using synchronized multimedia and the knowledge internalization system using portable virtual environment. In our proposed system, the education content is displayed in the immersive virtual environment, whereby a trainee may experience work in the virtual site operation. Provided that the trainee has gained explicit and tacit knowledge of casting through the multimedia-based knowledge transfer system, the immersive virtual environment catalyzes the internalization of knowledge and also enables the trainee to gain tacit knowledge before undergoing on-the-job training at a real-time operation site.

Key words : Knowledge Acquisition, Job Training, Technical Skill, Engineering Education, Virtual Reality, Casting

1. Introduction
In recent years, Japanese manufacturing industry has entered into a very competitive era due to globalization effect, and to the concept of manufacturing right-thing at right-place, whereby there is a tendency of manufacturing base relocation. At the same time, manufacturing system in Japan tends to change from conventional mass production, perpendicular work division system to high precision, small lot but multi-variety manufacturing system. On top of the effect of industrial hollowing due to manufacturing base relocation, depression of domestic demand due to over-dragged economy downturn too has caused the deterioration of manufacturing industry and its surrounding industries. Under this tough environment, survival is clinched to overcoming stringent requirements of quality, time and cost. With respect to this, small and medium industry, which is lagging behind in terms of good manufacturing environment, facilities and so on when compare with large-scale industry, has its productivity directly relies on its engineer/technician’s skills. Therefore, creation and transfer of skill/technology and training of an engineer/technician are vital, appropriate staff-training program based on long-term viewpoint should not be taken for granted(1),(2). Unfortunately, due to financial, man power and time constraints, under the tough situation mentioned above, it is very difficult for small and medium industry to organize a good training program. In reality, more than half of the small and medium industry implement On-the-Job Training(OJT), video library, tech-
nical document and so on in their training program. Nevertheless, these time consuming and inefficient methods do not make it easy for one to succeed the high-level skill of a skill technician. Considering the current and future conditions, such as aging of staff, outflowing of talented people due to industrial restructuring, declination of manufacturing mindset, shifting of paradigm towards 3K jobs (Kitsui/Tough, Kiken/Dangerous, Kitainai/Dirty), have caused the declination of young technician recruitment and the difficulties in creation and transfer of high level technical knowledge. By forecasting that deterioration of technology and skill is soon to happen, the creation and transfer of technology and skill is becoming a major agenda for most of the small and medium industry.

This paper proposes a new virtual reality based knowledge acquisition and job training system for casting design, which is composed of the explicit and tacit knowledge transfer system using synchronized multimedia and the knowledge internalization system using portable virtual environment. In our proposed system, the education content is displayed in the immersive virtual environment, whereby a trainee may experience himself in the virtual site operations. Provided that the trainee has gained explicit and tacit knowledge of casting through the multimedia-based knowledge transfer system, the immersive virtual environment catalyzes the internalization of knowledge and also enable the trainee to gain tacit knowledge before undergoing on the job training at real operation site.

2. Skill Worker Education Through the Sharing of Ba and Processes of Knowledge Transformation

2.1. Skill Worker Education through the Sharing of Ba

When conducting skill worker education, the concept of 'Ba' (which roughly means 'place') should be discussed because it is one of the important points that need to be considered. The Ba here does not only refer to the physical space, but the space of a particular time and space or the "relational space". In short, the key concept in understanding Ba is 'interaction'. In the skill worker education, the sharing of Ba in a particular time and space is very important. A more detail explanation will be, the sharing of skill worker who possesses high-level skill, and site operation. By sharing the above Ba, not only one may gains knowledge through his five senses, but knowledge that can only be gained by "attendance at the operation site", can be obtained too. Hence, the sharing of Ba is thought to be very useful, especially in the skill worker education. Nevertheless, there are some known problems of skill worker education by using sharing of Ba and they are stated as follows; (1)As there are some constraints and limitations exist in the sharing of Ba, in term of time, space and scale, the skill worker education may not be conducted efficiently. (2)Since the quality of educationalist greatly affects the outcome of the education, plenty of time may have been spent but satisfaction in education is hardly gained especially in current situation because the skill worker education is conducted under the constraints of time, money and human resource. (3)The trainee may not fully aware of the danger accompanied at the real operation site, accident may have happened due to the unfamiliar operations. Therefore, attention must always be paid during the education process that may impose a heavy burden on the educationalist. In this paper, we explain about the usages of portable immersive virtual environment. By using the system, the sharing of virtual and simulated Ba can be promoted, in which it is thought to be useful for skill worker education.

2.2. Processes of knowledge transformation

SECI model is one of the active models of knowledge management. There are 4 transformations processes of knowledge, namely (1)Socialization, (2)Externalization, (3)Combination, and (4) Internalization, which interacts the tacit and explicit knowledge and eventually helps to create new knowledge. The term SECI is taken from the initial letter of four processes. Knowledge can be divided into two parts, which are explicit knowledge and tacit knowledge\(^{(3)-(5)}\). In this paper, explicit knowledge is defined as "knowledge that can be ex-
pressed by document, charts and other formatted languages”, "knowledge that is based on general objective rule” and others, which is also equivalent to "technology”. On the other hand, tacit knowledge(6) is defined as "knowledge that can hardly expressed by document and charts”, "knowledge that is based on individual’s subjective experience”, which is also equivalent to "skill”. Through the processes of knowledge transformation, by transferring the tacit knowledge possessed by individual into explicit knowledge, the knowledge is made easier to be spread and this enable the sharing of knowledge within an organization. The endless iteration of knowledge transformation processes is called "spiral of knowledge creation”.

3. Casting Design and Skill Transfer

3.1. Outline of casting design

Casting, which is the product of the metal founding industry, is manufactured in a single procedure from liquid metal without any intermediate mechanical operations such as rolling or forging. This basic process, which is the most direct process among metallurgical processes, has provided the foundation for the growth of this vast industry by having a wide diversity of products. Casting design refers to the planning of manufacturing procedures and methods in order to manufacture products from the drawings or models, by taking into account factors of techniques and economics. Therefore, casting design is positioned at the top of all metal casting processes. As the outcome of the planning will naturally influence its following processes, thus making the casting design one of the main processes of all.

3.2. Process of casting design

Currently in the case of making small casting product, the process of making casting design is usually carried out in the meeting room while looking at the product shown in Fig.1(a); drawing the gating system plan on the floor of operation site by using chalk; or arranging the wooden pattern of runner as visual aid shown in Fig.1(b). In all cases, the casting design is in charged by skill worker, whereby at most of the time, the plans are based on previous plans, that have close proximity to the current product. During the casting design process, it is most desirable if the design of gating system is carried out by fully considering the factors of casting time and casting speed. However, most of the casting manufacturers fail to review the design in detail and merely rely on the know-how, intuition and experience of skill workers.

3.3. Education of metal casting skill and creation of new knowledge

In the metal casting processes, in order to manufacture a casting product, not only explicit knowledge such as technology and others are required, tacit knowledge such as skill is required. For designing and manufacturing highly value-added product, besides combining and gaining of explicit and tacit knowledge, techniques and skills regarding metal casting are to be learned through OJT. Figure 2 shows the usage of high-level skill transfer system and
the immersive virtual environment system corresponds to the knowledge transformation processes of SECI model. In this case, (1) Socialization refers to the process whereby user whom undergoing OJT or real site operation may aware of the existing problems and learn about tacit knowledge. (2) Externalization refers to the process whereby user whom using the high-level knowledge transfer system, gaining explicit knowledge through technical document, technical data and so on. (3) Combination refers to the process whereby user gaining knowledge through the combined display of explicit and tacit knowledge from video and others. (4) Internalization refers to the process whereby users owning the knowledge through self-study and self-action based on the knowledge through skill transfer system. In the processes of externalization and combination, high level skill transfer system is utilized. While in the process of internalization, immersive virtual environment system is utilized. By doing so, during the process of obtaining knowledge, creation of knowledge and gaining of new tacit knowledge are also made possible.

3.4. Advantages of our proposed system

Our proposed system incorporating cutting-edge technologies, such as virtual reality and robotics, is developed to assist day-to-day work on the shop floor by helping to hand down skills, train young engineers and produce high value-added products. The aim is to pass down skills and develop human resources more efficiently and effectively by combining the conventional documentation of technical information, video library and on-the-job training with our “knowledge transfer system” and “immersive virtual environment system”. The advantage is that the immersive virtual environment system allows users, who have acquired knowledge through the skill transfer system, to experience and acquire the technique and skills of veterans in a virtual environment. The system combines 3D visualization system and force feedback device, and allows users wearing 3D glasses to experience the hardness and the weight of a 3D virtual object. The user can acquire sophisticated skills intuitively and through his senses, by viewing images projected on the screen of a 3D visualization system and feeling the force delivered by the force feedback device simultaneously, which adds to the knowledge and skills he acquires on the shop floor. The system will be improved to allow users to use his five senses and to be utilized in a wider variety of manufacturing sites.

4. Education Support by Using High-level Knowledge Transfer System

Figure 3 shows the outline of high-level knowledge transfer system(7). By having the search and visualization functions, user may efficiently access to any desirable knowledge. Meanwhile, tacit and explicit knowledge are displayed by using SMIL(Synchronized Multimedia Markup Language) and explicit knowledge is displayed by using XML(eXtensible Markup Language). The keywords of the knowledge are anchored by links so that when needed, the related information or knowledge can be reached in an efficient manner. Moreover, the parts that the video fails to express can be complemented by the combined usage of 3D CAD and CAE simulators. In the usage of the system, user begins by using search and navigation functions, later the designated knowledge can be reached by accessing the search results or following the navigation. Knowledge that is categorized as tacit knowledge is displayed as multimedia flask powered by SMIL. On the other hand, knowledge that is categorized as explicit knowledge is displayed as text form powered by XML. Meanwhile, links are anchored to important keywords of the knowledge, in which user can access and gain the related knowledge when necessary. For those parts that cannot be explained by sole video image or sole text document, the combination of both medias allow both merits from two medias to be fully utilized. On top of that, the drawback of video image where by the understanding of content greatly depends on individual strength, is further enhanced by using 3D CAD data and CAE simulation. Through this system, the effect that cannot be obtained by using conventional shared knowledge transfer system and video library and others, is greatly expected.
Fig. 2 SECI model and skill transfer system
5. Internalization Support of Technical Skill Education by Using the Immersive Virtual Environment

5.1. Development of immersive virtual environment system

For the general immersive virtual reality system\(^{(8)}\), setting up the system faces constraints such as the space required is relatively big and the cost of setting up the system is extremely high. Moreover, the focus adjustment of 4 screens required some tedious setting, therefore, the shifting of entire system is not encouraged once the system is tuned up, not to mention that a high performance computer is required for the display of images. In order to solve the above constraints, a portable virtual environment system has been developed as shown in Figs. 4 and 5.

The portable immersive virtual environment system consists of two screens and four projectors. Compare to the general immersive virtual reality system, our proposed system is much more smaller in size and the focus adjustment of a single screen is relatively simple \(^{(9)}\). As the display software is installed into an ordinary PC, the total cost of setting up the whole system is relatively low. On top of this, by adding a force feedback device to the 3D
visualization device, user can really feel the weight of the 3D object displayed by the 3D visualization device. On top of having the visual sensation towards the object displayed in our proposed system, experiencing haptic sensation and force sensation can further promote the knowledge internalization regarding the subject of casting. Our proposed system is divided into two main parts, namely 3D visualization device and the force feedback device. The force feedback device consists of a multi-axis type manipulator. The 3D visualization device and the force feedback device are controlled by a single PC, thus allow synchronized execution.

In the 3D visualization device, the head tracking device embedded in the circular polarized glasses may feedback the position of viewpoint to the PC, thus enable the angle of object displayed to be altered in real time. On the other hand, in the force feedback device, the end effector position of manipulator and the load by the manipulator will be feedback to the PC. By taking these values and the shape of 3D image displayed in to concern, the position of the manipulator and torque are properly controlled, it is the linked up to the 3D stereoscopy image and feedback the force sensation to the users. By using the force feedback device together with the 3D visualization device, other expected effects are stated as follows; (1) The tacit knowledge that can only be gained at the real operation site can now be gained through the virtual reality experience. (2) Similar to the case where by only 3D visualization device is available, in the case where the trainee has yet to fully aware of the danger that may exist at the operation spot, the virtual system allow the education to be conducted in a safe environment. By using the immersive virtual environment, one can learn about the manufacturing through

![Fig. 5 Force feedback device](image)

![Fig. 6 Use of our proposed system](image)
Table 1  Specification of force feedback device

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<table>
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<tr>
<td>Degrees of freedom</td>
<td>5</td>
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<tr>
<td>Power requirement</td>
<td>500 [W]</td>
</tr>
<tr>
<td>Position resolution</td>
<td>$4 \times 10^{-6}$ [m]</td>
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<tr>
<td>Simulated equivalent inertia</td>
<td>2 [kg]</td>
</tr>
<tr>
<td>Force sensitivity</td>
<td>0.01 [N]</td>
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<tr>
<td>Maximum output force</td>
<td>250 [N]</td>
</tr>
<tr>
<td>Maximum simulated stiffness</td>
<td>$5 \times 10^4$ [N/m]</td>
</tr>
<tr>
<td>Maximum velocity</td>
<td>1.0 [m/s]</td>
</tr>
<tr>
<td>Maximum deceleration</td>
<td>50 [m/s$^2$]</td>
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5.2. Internalization support of technical casting skills

Figure 6 shows our proposed Cyber Assist Meister Robot system known as CAMRobot system that was developed as an option to reroute the current path of doom of small and medium industry. This robot can be used to train on product design, as the system is programmed with veteran skills of foundry factories. The robotic system as shown in Fig.7 and Table 1 also displays 3D stereoscopic images and equipped with a haptic interface for the user to virtually "feel" the foundry workflow. The robot is somewhat like a teacher that teaches the user master-level craftsmanship skills like one who would learn from a human master.

CAMRobot consists of 2 major systems for the user to acquire theoretical knowledge and practical skills: (1) "Knowledge Transfer System" to learn knowledge on foundry work (casting and molding). (Computerized touch panel system). (2) "Portable Immersive Virtual Environment System" to acquire practical foundry skills. (System consisting of virtual reality system and haptic device). The "Knowledge Transfer System" consists of a touch panel computer. It is designed for the user to swiftly learn all about foundry work, according to the user’s level of knowledge. On the other hand, the "Portable Immersive Virtual Environment System" is geared for the user to virtually experiencing the "actual" casting and molding pro-
Fig. 8 Ramming

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process. This system comes with two screens to show 3D stereoscopic images so that the user can “see” the workflow and a haptic device to enable the user to “feel” the workflow. Casting and molding consists of many procedures which briefly includes molding, mold assembly (as shown in Fig. 7), ramming (as shown in Fig. 8), pouring, and so on. However, these procedures are often difficult to explain by simply using documented descriptions and visuals because these are procedures that are nothing like anyone would experience on daily basis. The advantage of this robotic system is that it provides the user an opportunity to visually and haptically experience the foundry workflow in a virtually-real manner.

By combining the usages of CAMRobot and OJT, training program is expected to become a highly efficient and effective futuristic means of human resources development of engineers and technicians. When using the “Portable Immersive Virtual Environment System”, the user enters a “3D Visualized System”. By wearing 3D stereoscopic glasses the user can see a stereoscopic 3D image of the workflow, in which even the shape and form of a product can be experienced and “felt” by using the haptic system. Simply put, this system can be used as a system to support the internalization process of learning which is the Phase 4 of the knowledge conversion process defined by the SECI Model. There are many advantages in using this system for in-house education and training purpose. Notable advantages are: (1) The worker can virtually experience the foundry workflow prior to actually performing the works at the worksite in the foundry factory. (2) Learn about the work procedures beforehand. (3) Fully learn about the risks and danger throughout the work process. (4) Train beginner/intermediate level workers that haven’t reached veteran level yet, so they can smoothly perform their tasks at the worksite.
6. Conclusion

In this paper, a prototype of an interactive high-level skill transfer system has been developed using multimedia and virtual reality technology. In conjunction to this, skill technicians from the field of casting technology have evaluated this interactive system and its knowledge expression methodology that combines the explicit and tacit knowledge. Also, by using the immersive virtual environment system, one could learn about the making of metal casting through the multimedia technology and later experience the skill and know-how through the virtual reality technology.

References