Skill Analysis of Highly Skilled Worker in Optical Fiber Fusion Splicing

Takuo Kikuchi

Information and Communication Engineering Unit, Polytechnic University, Tokyo 187-0035, Japan

Abstract: In this study, information related to optical fiber fusion splicing skills is consolidated by extracting explicit knowledge of the proficiency levels of skilled technicians in two ways. The first is to visually capture and quantify those skills by identifying differences in the skill levels of a nationally certified technician and a highly skilled expert technician using motion capture software, the other is to explore the relevance of the operation and thinking processes by interviewing the expert technician and then attempt to quantify empirical tacit knowledge by an analysis of mobile tracking views using motion capture software. The results show that a technician's ability to engage in "sensory thinking", such as the proper management of visual and tactile cues, is the most important component of his or her proficiency during optical fiber fusion splicing operations, and it was clear that operations were complemented when work path movements were reduced.

Key words: Skill analysis, fusion splicing, optical fiber, highly skilled worker, explicit knowledge.

1. Introduction

Recently, there has been growing interest in network quality because the data quantities traveling over information networks are increasing exponentially. However, it is seldom realized that the quality of the cabling performed during network construction is one of the most significant factors affecting network quality. For instance, a previous study indicated that approximately 70% of all network accidents are caused by lack of quality cabling [1]. When optical fibers are used, installation quality is particularly dependent on the skill of the installer because the splicing and connections of optical fibers is extremely sensitive. However, to the best of the author's knowledge, there have been few reports that focus on analyzing fusion splicing performed by skilled workers. This is because, in fusion splicing work, multiple processes are combined and it is difficult to extract explicit knowledge related to the motions of the technicians and variations in the

objects being handled. However, a number of previous reports have focused on the analysis of skills required for various other crafts and professions. For example, in a skill analysis involving chrysanthemum kneading, a CG (computer generated) model was used to trace a joint in order to determine 1) the stability of the joint at the time of work, and 2) the relationship between the finished work and the skill of the craftsman [2]. In addition, in a study involving a welding learning system, students were provided an example of proper behavior via instructions to write down information related to the height, speed, and the amplitude of a working gas welder, in chronological order, and to check for discrepancies [3]. However, while explicit knowledge of highly skilled workers has been studied in a variety of special skill sets, the methods used in these studies remain subject to discussion. For example, there is a lack of consensus regarding the defined quality and whether the skills demonstrated represent the best practice [4-6]. The author has also studied various training methods used for producing skilled workers [7-10]. One such study involved skill analysis and dynamic modeling of information network cabling work. In Ref. [7], fusion splicing and

Corresponding author: Takuo Kikuchi, Ph.D., associate professor, research fields: telecommunications, vocational ability development.

storing, which are difficult and require both expertise and experience in optical fiber cabling, were analyzed. In that study, an analysis of skilled worker and beginner actions was performed using motion capture software and differences in skill levels were identified. Following the study, the author's observations and his analysis of the work methods utilized were consolidated in included in manual for training beginners.

This paper deals with an analysis of the motion and thinking processes of an highly skilled worker who was a gold medalist of the World Skills competition [11] and a technician certified via the Japanese National Skills competition [12]. The result will be used to clarify the relationship between skill and quality. Using this approach, not only is it possible to compare the performance of skilled and unskilled workers, we can also compare the abilities a highly skilled expert and a properly certified technician in order to precisely determine the characteristics that differentiate the two. Simultaneously, an interview will be conducted with the highly skilled expert, and an attempt will be made to clarify the empirical tacit knowledge of the certified technician from an analysis of the relationships between the operating and thinking processes of both [13]. Additionally, in order to extract heuristic tacit knowledge of the highly skilled expert, this paper will present the relationship between motion and thinking processes by listening to the observations of the certified worker. After donning a wearable camera (Panasonic HX-A500, see Fig. 3 (a)) equipped with an eye tracking function and a recorder unit, the certified worker will perform a technical process involving a high degree of skill, and the demonstrated empirical tacit knowledge involved will be summarized.

In the next stage, this will be done to determine what kind of impact the expert technician's proficiency level has on the process, and to discuss changes that may result if technicians change from a piece of equipment (to which he or she is accustomed)

to an unfamiliar piece of equipment. The present study will then discuss optimizing work, which has a significant effect on network quality, and which deals with the relationship between skill and quality. From these results, the abilities required to perform optical fiber fusion splicing work at the expert level are expected to be clarified and reported.

2. Analysis Method

2.1 Fusion Splicing

Telecommunications cabling consists of a variety of work processes that must be performed when installing an information network system. Among those, especially in optical fiber fusion splicing work (which is a common method of creating optical fiber connections in access and backbone cables in a building) requires a high degree of expert ability. However, optical fiber cabling work is very difficult because the fiber is very thin and an insufficient degree of handling skill is likely to cause unevenness in the cabling quality. Therefore, the processes demand technicians that possess high levels of skill. While we identified approximately 16 processes involved in installing fusion splicing in trays, as shown in Fig. 1, they can be further classified in terms of preliminary procedures, fusion splicing, and storing processes.

Fig. 1 Fusion splicing process.

The processes of removing the jacket, cleaning, and then cleaving the fiber, which are important for ensuring connection quality, are included in the preliminary procedures of optical fiber installation. However, since these pre-processes are common to other forms of optical fiber work besides fusion splicing work, this study will focus on setting fiber and fusion splicing, which are the most important components of fusion splicing itself.

2.2 Work Procedure

In order to perform skill visualization, it is necessary to analyze the object of skilled work under normal conditions, without imposing extraneous procedures. Therefore, the technicians were asked to repeat each targeted procedure (shown in Fig. 1) three times, after which the results were analyzed by visualization. In order to ensure objectivity, the work process was the same used in the Ministry of Health, Labour and Welfare top level, 1st Grade National Trade Testing [14]. As previously noted, persons who pass the 1st grade tests are certified as skilled technicians. In this procedure, various rules are set, such as the number of times the optical fiber is to be cleaned, procedures for cleaning the cleaver, and the maximum acceptable connection loss value (0.5 dB/per number) [15].

In addition, the splicing speed of the acceptance criteria of this assay is approximately 120 seconds/connection.

2.3 Analysis Procedure

An overview of analytical procedure used in this paper is described in the following steps.

Step1: Analysis of the heuristic tacit knowledge of the highly skilled worker

First, an overview of the heuristic tacit knowledge of the highly skilled expert is extracted from the standpoint of his motions and thinking processes, after which the thinking process and work contents are analyzed. Next, the relationship between the cabling

work speed and the installation quality is estimated from the differences noted in each work process.

Step 2: Visualization and skill comparison

This research step focuses on the skill level differences between the highly skilled expert and the certified technician by digitizing the skills observed via motion capture software (MOCAP).

Step 3: Analysis of motion process of highly skilled expert

This research step focuses on the relationship between the eye track and work via eye tracking analysis. Motion analysis was also used to measure moving distance. By digitizing a technician's fusion splicing work, the difficulty of each work process can be clarified.

2.4 Analysis Targets

To gain an understanding of the difference in skill level between certified technicians and highly skilled experts, we ask a Gold Medalist of World Skills London 2011 and a certified technician who had competed in a national skill competition to participate in our experiments. It should be noted that World Skills is an international skills competition held every two years to determine the world's most skilled person in a variety of fields. However, since there has been no previous analysis the skills required by a tournament champion, there could be questions regarding what reference should be set for "skilled technicians".

Fig. 2 Equipment and preparation for fusion splicing.

3. Skill Analysis

3.1 Analysis Heuristic Tacit Knowledge of Skilled Worker

Heuristic tacit knowledge levels are analyzed using the results of our interviews with the highly skilled expert [13]. From these results, as shown in Table 1, the primary parts of optical fiber fusion splicing work were extracted and the real relationship between the work and other points of consideration were determined. The “consideration process” is the result of extracting tacit knowledge from the highly skilled worker. We found that the highly skilled worker minimized each motion process during the “control” adjustments in order to perform optimization based on obtaining “sense” information. Furthermore, from the results, we found that as the number of “controls” increases, so does the skill level.

For example, the highly skilled worker controls the moving route, angle, and position during the

movement to place the holder in the fusion splicer. These placing movements are considered to be a thinking process. The moving route is used to set the holder into the fusion machine, the angle is the angle used to orient the holder, and the position is the position of the holder. It can thus be seen that, in order to carry out this level of control, it is necessary to rely on visual, tactile, and hearing cues. This shows that those skill levels can be controlled by a so-called sense, and it is presumed that this is an empirical tacit knowledge needed to demonstrate expert skill levels.

3.2 Formulization of Skilled Technician's Thinking Process

3.2.1 View Tracking Experiment

In this section, in order to clarify the differences between the highly skilled and certified technicians from visual cues, view movement analyses were conducted on the works produced by both technicians based on the empirical tacit knowledge shown in the

Table 1 Heuristic tacit knowledge levels of the highly skilled expert.

			Work		
			Moving holders	Set holders	Splicing
CRITERION			Uniformity position?	Correct fiber gap? Hit fiber?	Error? *1
Motion process	OPERATION *2		Hold holders with both hands Move holders to splicer	Put holders Put fiber to V-groove Fix holders	Push a botton
	CONTROL *3		Holding position Holding angle Moving route	Holding angle Angle and position for setting holders	Cleaning V-grove Set parameter
Thinking process	SENSE *4	VISION	Position Angle	Position Angle	Fiber alignment Angle and gap of end surfaces Seeds or inclusion
		TACTILE			External environment (temperature, humidity)
		TOUCH		Feeling	
		HEARING		Sound	Sound
	KNOWLEDGE *5		Influence on quality when the item of "CONTROL" was controlled.		

The ※ marks in the figure above refer to the following items:

※1 Representing the operation of each task.

※2 Points that should be controlled in each work. Places where caution is necessary.

※3 What a skilled technician feels at each step of the work.

※4 Knowledge that each skilled technician has obtained from each work. Implicit knowledge. If this is insufficient, the control of ※5 will not be smooth.

previous section. The pre-process has numerous procedures that workers must visually inspect properly, and their visual field motions were found to depend on their skill levels. Visual field conditions were extracted via the previously discussed wearable camera (Fig. 3 (a)). Fig. 3 (b) shows the visual field of the camera. As can be seen in this figure, the entire working area is within the camera's field of view.

The test result is shown in Fig. 4 and Table 2. The domain shown in the circle of Fig. 4 is the object area, and movements are shown in numerical order. The line shows visual field movements in the area. According to Fig. 4, the highly skilled worker performed a visual field movement survey eight times (Fig.4 (a)), while the certified worker conducted 15 visual

surveys (Fig.4 (b)), approximately double the amount of the certified worker. The distance that the highly skilled worker's hand travels is 1,600 mm, while the certified worker's hand travelled 2,200 mm. This indicates that there is strong correlation between hand distance travel and work time.

The amount of time a technician's attention remains focused in the visual field can be used to determine whether the worker is watching only a few points within the view. We found that time durations were

Fig. 3 Eye tracking system using wearable camera.

Fig. 4 Eye tracking result comparison [13].

Table 2 Visual field tracking analysis [13].

	Highly skilled worker	Certified worker
Visual field movement in an object area	8	15
Visual field staying time	Short	Long
Movement distance between each work	16	22
Degree of association	1	0.93
Work time [sec]	24.0	47.6

longer for the certified worker than for the highly skilled worker. If a work place and a visual field match, then the ratio was set to 1. If not, the ratio was set to 0. The average was examined as a degree of association. The average ratio related to a real work place and an actual visual field was investigated under the assumption that if they match, then 1 would be returned, and in other cases 0 would be returned. The average ratio of the highly skilled worker was 1, while that of the certified worker was 0.93. This result suggests that the certified worker tends to shift his gaze to a number of different points other than the actual work place, while the highly skilled worker's view is more firmly focused on the work and the worker's hands move in shorter distance increments. In other words, as the worker's skill level increases, hand scrolling movements and extraneous eye motions decrease.

3.2.2 MOCAP Motion Analysis

In this study, PV-Studio Character motion capture software was utilized. We put a marker and a joint at sixteen joints and the fingertips of the highly skilled and certified workers, and then used the results to reproduce their fusion splicing work three-dimensionally. We then overlapped the behavior of both workers and analyzed differences from their body movements and work products. Imagery was

Fig. 5 MOCAP system.

(a) Data points

(b) Frame of arms using MOCAP

(c) Put the frame of two experts on top of one another

Fig. 6 Data visualization.

captured using two cameras, which were installed on both sides of the workers, as shown in Fig. 5. Fig. 6 shows examples of skill analysis using motion capturing software.

The data points are shown in Fig. 6 (a). A total of

eight points at the worker's elbow, wrist, thumb, and index finger were set and their movements were captured. First, we focused on the work difference between the two technicians when the same fusion splicer was used. The target work was the set folder shown in Fig. 7. Based on the figure analysis, this work requires an especially strong level of empirical tacit knowledge of fusion splicing.

A graph showing elbow and wrist distance movements in the XY plane is also shown in Fig. 8. The vertical axis represents the point movement amount (cm), and the horizontal axis represents time. The movement amount is the difference from the current to the previous point. Each graph represents the expert's left and right arms movements viewed from two points. The red lines represent the x and y axes of left arm, while the green lines represent the x and y axes of right one.

The time required for setting the holder in place is shown in Table 3. According to these figures and tables, there were few observed differences between the required times, and the differences between moving distances in the XY direction were small. In the next step, an experiment was conducted using a different fusion splicer. It was thought that if a skilled worker was controlled by sense, shifting workers from their familiar splicers to different splicers would produce behavioral differences. This process was also used to gain an understanding of how getting accustomed to using something new relates to proficiency. The results are shown in the Table 4 and Fig. 9.

The results showed that there were very few differences when using other equipment as opposed to using familiar equipment. However, the work time was less for the highly skilled worker. Furthermore, moving distance in the XY plane was small and hand movements followed the shortest path, thereby leading to a shortening of work time. Therefore, it can be presumed that the expert skills involve tacit knowledge, and even when there is a model change,

the highly skilled worker quickly adapts and produces the optimum operation based on senses.

Fig. 7 The work of "Set Folder".

(a) Highly skilled worker

(b) Certified worker

Fig. 8 XY fluctuation graph of elbow and wrist distance.

Table 3 Time required for splicing and setting the folders comparisons.

	Total splicing time [sec]	
	To set folders	
Highly skilled worker	27.11	1.21
Certified worker	28.22	1.49
Beginner	49.12	1.78

Table 4 Time required using a different fusion splicer.

	Total splicing time [sec]	
	To set folders	
Highly skilled worker	32.67	1.78
Certified worker	34.38	2.21

(a) Highly skilled worker

(b) Certified worker

Fig. 9 XY fluctuation graph using a different fusion splicer.

4. Conclusions

In this paper, an analysis of highly skilled workers engaged in optical fiber fusion splicing work was performed, and the work mechanisms were elucidated. Skills analyses of highly skilled and certified workers were carried out by (1) visualization comparisons of skills utilizing the motion capture software, and (2) comparisons of the view movements of a head-mounted camera. In addition, formulation was applied to the analyses of the operation and thinking process of certified workers in order to gain an understanding of the skills they had mastered. As a result, it was determined that an important factor related to expert skills in optical fiber fusion splicing operations is “sensory thinking”, which can be defined as the appropriate use of visual and tactile cues, and that the expert operations are complemented when the movement path required to accomplish an action is minimized. It is anticipated that this investigative approach will be applied to other information wiring

construction work in order to formulate processes that will facilitate the construction of quality information networks. A detailed analysis of fusion splicing procedures will be presented in a future paper.

Acknowledgement

The author would like to express the deepest appreciation to medalists and competitors of skills competitions who cooperated to these analysis experiments. This work was supported by JSPS KAKENHI Grant Number JP16K01054.

References

- [1] Fluke Networks. 2013. “Knowledge Base.” Accessed June 10, 2013. <http://www.flukenetworks.com/knowledge-base>.
- [2] Abe, M., Yamamoto, T., and Fujinami, T. 2003. “An Analysis of the Physical Movements in Acquiring a Skill Using a Motion Capture Device (in Japanese).” In *Proceedings of JPSA 2003*, 2: 351-2.
- [3] Fujita, N. 2007. “Torch Operation Learning System Based on Welding Skill Parameters (in Japanese).” *IEICE J90-D* (9): 2522-9.
- [4] Furukawa, K., Masuda, T., and Kobayashi, I. 2011. “Abductive Reasoning as an Integrating Framework in Skill Acquisition.” *Journal of ACIII* 15 (8): 954-61.
- [5] Aiba, E., Kazai, K., Shimotomai, T., Matsui, T., Tsuzaki, M., and Nagata, N. 2011. “Accuracy of Synchrony Judgment and Its Relation to the Auditory Brainstem Response; the Difference between Pianists and Non-Pianists.” *Journal of ACIII* 15 (8): 962-71.
- [6] Enokibori, Y., and Mase, K. 2013. “Reproduction of Expert’s Subjective Skill-Level Evaluation with Wearable Acceleration and Gyroscope Sensors on Metal-Filing.” *Journal of JASI* 2013 28 (4D): 391-9.
- [7] Sugita, D., and Kikuchi, T. 2014. “A Method of an Efficient Installation Process for Generic Cabling inside Customer Premises.” In *Proceedings of 1st International Conference on Intelligent Green Building and Smart Grid*, 214-5.
- [8] Kikuchi, T. 2014. “Designing Comprehensive FTTH Training Program throughout Japan and the World.” Presented at the Asia-Pacific conference 2014. FTTH council.
- [9] Kikuchi, T. 2003. “Consideration about the Vocational Training in the Field of the Information Network Cabling (in Japanese).” In *Proceedings of Practical Technology and Education*, 34-5.
- [10] Kikuchi, T. 2015. “Designing a Comprehensive Skill Evaluation and Vocational Ability Development Program

- for FTTH Installer.” *Journal of Computer Technology and Application* 6 (1): 5-13.
- [11] World Skills International. 2014. “Skills Competition.” Accessed April 11, 2014. <http://www.worldskills.com/>.
- [12] Japan Vocational Ability Development Association. 2014. “National Skills Competition.” Accessed March 9, 2014. <http://www.javada.or.jp/jigyoin/gino/zenkoku/>.
- [13] Kikuchi, T. 2015. “Analysis of Optical Installer’s Skill and Quality of Installation.” *IEICE Technical Report, OFT2015-7*: 31-4.
- [14] Ministry of Health, Labor and Welfare. 2014. “Vocational Ability Development.” Accessed April 2, 2014. <http://www.mhlw.go.jp/>.
- [15] Advanced Info-Communication Promotion Committee. 2014. “Ginokentei information.” Accessed September 5, 2010. <http://www.b2every1.org/kentei>.