



Research Article

Exploring Features of the Unconscious in Quality Inspection in Manufacturing

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ARTICLE INFO

Article History

Received 13 December 2021

Accepted 08 April 2023

Keywords

Skill transfer

Experienced worker

Reciprocal motion

Quality inspection

Manufacturing

ABSTRACT

In quality inspection, which is the final stage of the manufacturing process, there is an operational manual on how the object should be inspected. In this study, we followed the gaze of the workers to search for the "way of looking" at the objects to be inspected, which is not described in the manual. As a result of experiment, we found a difference of the reciprocating eye movements between skilled worker and the beginner. It is suggested that this indicates a way of looking at inspection that has been unconscious until now.

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1. Introduction

With the widespread use of IoT and AI, robotization has made remarkable progress in manufacturing processes, but the gap in labor productivity at small and medium-sized firms, which are inferior to large firms, is unfortunately widening [1]. As a matter of fact, there are still many handy manual operational processes in the sites of SMEs, and human resource development through improvement activities and creativity is required. For this reason, the authors have been conducting research on organizational learning in SMEs in terms of the skill transfer and improvement of work efficiency [2].

While daily improvement activities are being carried out at workplaces, the reality of efforts to improve work efficiency is that they are often focused on work procedures, which are merely defined in work instruction handbook. Therefore, the authors decided to focus on quality inspection, which is greatly influenced by human resources, and to analyze both the skilled worker and the

beginner in consideration of human resource development. SMEs do not have an abundance of sufficient human resources and their inspection team is obliged to be slim. Therefore, an experiment was conducted with limited subject, i.e. one skilled worker as a benchmark and one young beginner as a comparison. At this time, we believe "work procedures" are insufficient for quality inspection, and how do they actually inspect the precautions written in the work instruction handbook? Hence, the authors have come into consideration that gaze measurement would be effective against visual inspection, and conducted an experiment using eye tracking system in this paper.

The history of gaze measurement is very old. In the past, the direct observation method was used to observe the movement of the cornea and capillaries with the naked eye, and the afterimage method was used to project the generated afterimage on the retina onto a screen and quantitatively measure the movement [3]. When it comes to the current direct observation method, for example,

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Tobii Technology's Tobii Pro Glass 3, has 16 LEDs and 4 eye cameras built into the lens to measure eye movements [4], and we take this Glass as a tool to observe eye tracking for quality inspection worker in a manufacturing factory.

The type of gaze can be further divided into three, such as Tremor, Drift, and Micro-saccade [5]. Tremor, as a small back-and-forth motion, makes observation difficult. Drift is the initial gaze that occurs simultaneously with Tremor or during Micro-saccade, which is a short and fast viewpoint motion to correct Drift [6].

2. Quality Inspection of Fuel Cell Piping

The pipes used in household fuel cells are long and narrow. Since the pipes are bent at several points, the quality inspection has to be done manually (Figure 1). In other words, inspection by machine is currently difficult. The fittings at the edge of the pipe and the exterior are inspected for scratches, dents, deformations, and other abnormalities. In this process, the bent parts are inspected for wrinkles, and the fittings of both edge sides of the pipe in particular are slightly protruding, making them difficult to see from some angles. For this reason, we look at the edges from various angles to see if there are burrs, scratches, dirt, etc., and if so, we polish them with a file or brush. Once the five products that have passed the appearance inspection are assembled, they are placed in a neat row and inspected again for comparison of appearance.



Figure 1: Image of piping (actually 3D instead of 2D)

In this paper, with the cooperation of Nihon Pipe System Co., Ltd. the workers of visual inspection of fuel cell piping were asked to wear glasses for eye measurement and to perform ordinary quality inspection work.

3. Methods

The gaze measurement experiment was carried out as follows.

- Location: The factory of Nihon Pipe System Co., Ltd.

- Date: Tuesday, August 3, 2021
- Workers: 1 experienced worker (the most skilled worker) and 1 novice worker as a beginner

As mentioned above, the object of the quality inspection is the piping of the fuel cell, and the final product is the eco-cute. We paid attention to the edge where the notes on the test were written and observed carefully while playing back the gaze measured video. In order to capture changes in a particularly short period of time, the video was played back at 1/16th the normal speed.

4. Result

As a result of the eye-tracking of the experienced operator, the quality inspection of 15 pipes in 377.56 seconds was recorded. The average speed of the inspection was 20 seconds per pipe, although there were some inspections of five pipes side by side for comparison and re-inspection of one of the 15 pipes.

In eye-tracking, fixation is often extracted and the location of the gaze is observed. However, since the time required for the quality inspection of piping is so short that the extraction of fixation is limited, we decided to capture the movement of the eye and follow its trajectory. Among the inspection processes, we focused on the inspection of both side edges, which requires changing the angle of gaze, and found that the longest time was 0.521s while the shortest was 0.181s, before polishing the edge. The results are shown in Figure 2 viewing the edge from the front, and Figure 3 viewing the edge from the side. We can see that both eye movements look like a reciprocating motion.

As for the pipes that were noticed during the visual inspection, those pipes are to be polished with a brush to remove burrs. Immediately afterwards, the edges are held with both hands to check its condition after polishing.

The step after polishing the edge for approx. 2.0 second was slightly longer than the step before polishing with a gaze period of 0.902s as shown in Figure 4. This phenomenon is understandable as it is a check on workmanship.



Figure 2: Experiences worker's inspection of edges before polishing (The duration is 521ms)

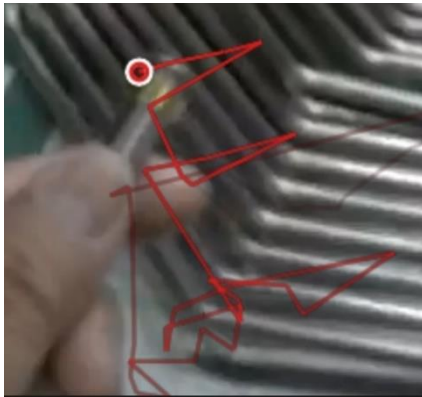


Figure 3: Edge inspection of experienced worker before polishing (The duration is 181ms)

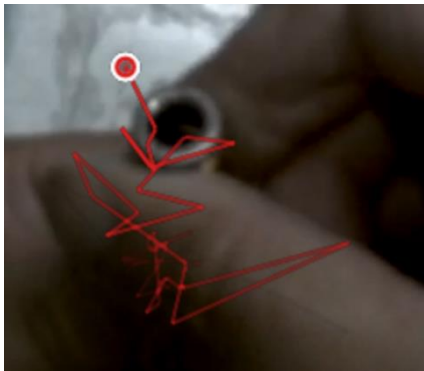


Figure 4: Edge inspection of experienced worker after polishing (The duration is 902ms)

In any case, the phenomenon that skilled worker reciprocate remains the same, whether before or after polishing the edge.

Now, let us look at the trajectory of the beginner's gaze. When viewed from the front of the edge after

polishing (Figure 5), the time taken was 881ms, which is nearly the same period as for the skilled worker, but its amplitude seems to be narrowly staring. Viewing from the side (Figure 6), however, it was found to take 2,143ms, which is more than twice as long as for the skilled worker. Also, we found that the degree of reciprocating is considerably less than that of the skilled worker.

Since the time required for the inspection was very short, it turned out that the workers themselves were so unconscious that they were not even aware that they were reciprocating gazes.

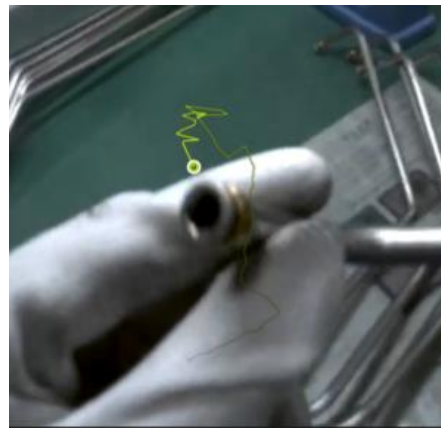


Figure 5: Edge inspection of beginner after polishing (The duration is 881m)



Figure 6: Edge inspection of beginner after polishing (The duration is 2,143ms)

5. Discussion

Looking at the gaze trajectory of the skilled worker and the beginner, there are certain differences in the reciprocating features as mentioned in the previous section. That is, skilled worker reciprocates while inspecting, but beginner does not. The reasons for this

cannot be determined from this experiment, as they are hidden in ones' unconscious. However, the beginner may be "an inspection is to stare intently" and may be committed to a single point of concentration. Skilled worker, on the other hand, may subconsciously be more intent on "finding defects" than on staring.

There is another interesting difference between the two. That is, when looking at the edge, either from the side or from the front, the "length" of the gaze time is reversed, i.e., beginner spends more time on the side than front, while skilled worker spends more time on the front. It is assumed that it is easier to find burrs from the front, although the side can be seen over the entire edge, where beginner tends to unconsciously looking at. However, the skilled worker might have the habit of looking at the front as an experience of the workmanship checkpoints.

The above discovered hypotheses are simply represented in an imaginary diagram as shown in Figure 7, where the inspection time is likely to be convex upwards and steadily decreasing, and is expected to become shorter, since knowledge is gradually accumulated through one's experience. The way in which they stare is thought to be a gradual, unconscious effect of reciprocal movement through experience, which would be truly tacit knowledge. This suggests that the degree of reciprocal motion would be a convex downward and right upward shift.

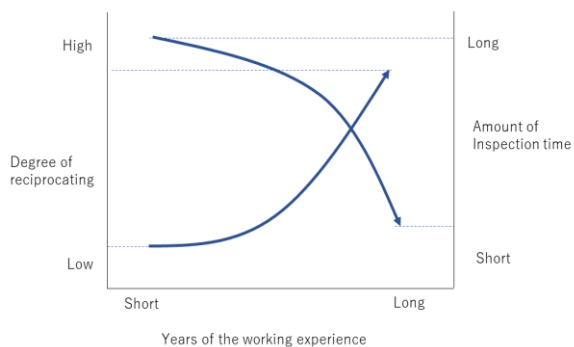


Figure 7: Image of trajectory depending on years of experiences

Here, let us consider the reason for the reciprocating motion of the eyes in quality inspection. Denso Corporation is using eye tracking for inspection at some manufacturing sites called Nishio-Seisakujo, where the key point of the test is to let the gaze flow as if spelling out the letter "2" as shown in Figure 8 [7]. It can be broadly interpreted as a reciprocal motion of the eyes.

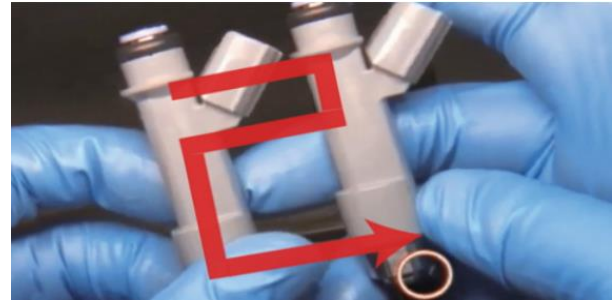


Figure 8: Key points of quality inspection at Denso (citing inspected images from [4])

The above interpretation might support the following four points which could be inferred.

First, since the act of searching for a problem is a part of the normal inspection process, the pattern of concentrating on a fixed point may not be possible. Rather, the fixed pointed gazing pattern may occur after a flaw as an example is found in a quality inspection.

Second, the remarkable factor is the reciprocating motion. At first glance, it appears as if the subject is going through a trial-and-error process of looking at the target and then checking it again while slightly moving backward. However, since this is done in a very short period of time, less than one second, it can be inferred that the reciprocating motion of the eye itself is unconsciously performed.

Third, the question is whether the reciprocal motion of the eye is left-right, up-down, or diagonal for experienced worker. In Figures 3 and 4, the eye movements are generally left-right, although there are some angular variations in the eye movements. On the other hand, in Figure 2, the gaze is up and down, and the reciprocating motion is quite short. This may be due to the difference in the shape of the object and the angle at which the gaze flows.

Fourth, with regard to inspecting the edge of the pipe viewing from the front of the edge as if you were looking at the cross section of the pipe, it takes more time than setting the pipe on its side looking across the edge, as mentioned in the section of result. The cross section is checked against the circumference of pipe, while the side is in a sense a straight line. This may have an effect on the speed. In addition, it is easy to understand that it takes more time to brush the same section after than before.

The reciprocating motion of the eye in this paper may be Tremor, Microsaccade, or Drift, but it needs to be

further explored in the future. The fact that the reciprocating direction of Gaze is not up and down but left to right and back and forth, may be due to human physiological factors. This is an issue for future research.

In this paper, we focused on the edge of the pipe, but we also observed large reciprocal eye movements such as ①→②→③ and ③→②→① when we viewed the pipe from the side as shown in Figure 1.

The most interesting feature of these reciprocating movements of the eye is that even in a very short time, decision-making could be executed to evaluate the test results. That means, even though the reciprocating movements are unconscious, judgments are made consciously by individual. This might be similar to driving a car, where instantaneous judgement, its evaluation and one's decision-making, are carried out simultaneously.

6. Conclusion

In this paper, we visualized and discussed the eye movements during the quality inspection of piping. Reciprocating eye movements were found during the quality inspection, although unconsciously, and the factors behind them were discussed. The analysis is based on the measurement results of only one experienced worker and one beginner, and the limitation is unavoidable. The bottleneck is that it is not possible to obtain a large number of samples due to the limited number of workers for quality inspection. However, as stated at the beginning of this paper, SMEs do not have enough human resources and have to make the most effective use of their limited management resources, particularly employees. Therefore, further study intends to increase the number of inspections in the future to make skilled worker as benchmark, and to consider modelling based on Figure 5 to assess skills more quantitatively.

We would like to address research on the visualization and analysis of the differences between experienced and beginner workers by means of modelling the gaze movement, which we expect to lead to the skill transfer.

Acknowledgements

This paper was made possible with the understanding and cooperation of Mr. Tano, President of Nihon Pipe System Co., Ltd. We would like to express our sincere gratitude to all of them including the subjects.

This paper has been supported by Grant-in-Aid for Scientific Research (JSPS KAKENHI Grant Number 17K03872 and 19K03062) and Grant-in-Aid for Specially Promoted Research from Chuo University.

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Authors Introduction



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