An Experimental Study of the Effect of Patrol Inspection Strategy for Improving Detection Rate of Abnormality of Industrial Plants

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ABSTRACT

Safe and stable operation is very important in large-scale plants. Patrol inspections are comprehensive and frequent on-site inspections and are indispensable works because early detection of a malfunction or failure of a component is desirable to achieve safe and stable operations. This study supposed that the detection rate of anomalies by patrol inspections is related with not only the amount of knowledge about plants but also the modalities such as vision and listening that are conscious during inspections. This study experimentally examined the difference in the detection rate of anomalies depending on patrol inspection strategies. In the experiment, a simulated small plant using the devices that are similar to plant components was constructed as a site for patrol inspections, and two types of patrol inspection strategies were examined: visual strategy that focuses on watching component conditions and auditory strategy that focuses on listening abnormal sounds. Fifteen volunteers participated in the experiment. The relationship between patrol inspection strategies and the approach and performance of patrol inspections were investigated by observing patrol inspection behaviors of participants and measuring their anomaly detection rates. As the results, although there was a small difference in the detection rate for visually detectable anomalies, the effect of the auditory strategy was suggested to improve the detection rate for not only auditory detectable anomalies but also visually detectable anomalies.

1. INTRODUCTION

Safe and stable operation is very important in large-scale plants. Patrol inspections are comprehensive and frequent on-site inspections. One of important purpose of patrol inspections is to detect a malfunction or failure of a component as early as possible. Many large-scale industrial plants in Japan were built in 1970s. Therefore, some of components are old and are required careful maintenances. In fact, there happened some serious accidents due to inadequate maintenance. In patrol inspections to prevent accidents, it is desirable to detect all abnormalities before they give serious influences on plant itself and its environment.

In the related work [Yokota, 2021], the difference in patrol inspection performance between young and experienced inspectors are concluded to relate with the amount and quality of knowledge about plants and the amount of knowledge used in the process of determining inspection points.

This study supposes that the detection rate of anomalies by patrol inspections is related with not only the amount of knowledge about plants but also the modalities such as watching and listening that are conscious during patrol inspections. In this study, the modality that is mainly conscious in a patrol inspection is called as patrol inspection strategy. There are two main patrol inspection strategies: visual strategy that focuses on watching component conditions and auditory strategy that focuses on listening abnormal sounds. This study experimentally examined the difference in the detection rate of anomalies depending on patrol inspection strategies.

The following of the paper describes an artificial setup constructed for conducting a task that is similar to patrol inspections, experimental procedure, experimental results, and discussions. Finally, the paper summarizes conclusions obtained from this study.

2. EXPERIMENTAL SETUP FOR PATROL INSPECTIONS

This section describes an artificial setup constructed for conducting a task that is similar to patrol inspections. The

experiment is approved by the ethical committee of the department of authors.

2.1. Artificial setup for a task similar to patrol inspections

Because it is difficult to conduct experiments of patrol inspections in a real plant, this study constructs an artificial setup that is similar to a plant. The requirements of the artificial setup are

1. The setup is composed of components and devices that are similar to those of a real plant,
2. Components and devices are placed in a space with some extent,
3. There are at least ten components and devices,
4. Anomalies can be detected by visual or auditory modality,
5. There are some works to read indicators that present the conditions of components and devices, and
6. A same task environment as a real plant can be provided.

Considering the requirements mentioned above, the authors newly construct an artificial setup in an experimental room. The components and devices used in the artificial setup are

1. six electric supply units (Size: 100 mm wide, 100 mm high, and 400 mm in depth),
2. four 19-inch liquid crystal displays indicating simulated plant conditions,
3. two oscilloscopes, and
4. a semi-scale experimental plant that simulates a boiler-type thermal power plant.

The components and devices of the artificial setup are arranged as shown in Fig. 1.

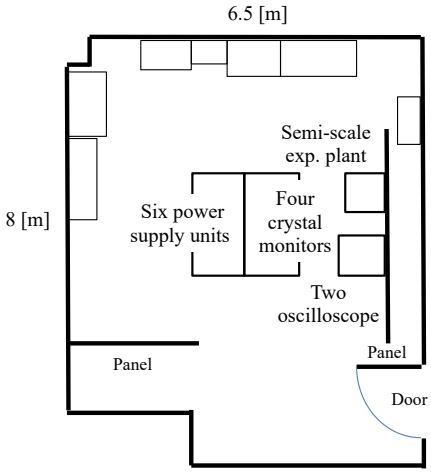

Figure 1 Arrangement of the semi-scale experimental plant and devices in the experiment room.

The size of the semi-scale experimental plant is 600 mm wide, 1800 mm high and 600 mm in depth. As shown in Fig. 2, it is composed of two pumps, two motor valves, three manual valves, two flow sensors, a simulated boiler with a heater, a mixer, and a thermo-meter, two water tanks, a cooler, and a field control panel with switches. Although it can be operated remotely by a computer with a control interface system, the function is not used in the experiments.

Figure 2 Semi-scale experimental plant.

2.2. Anomalies of artificial setup

Several anomalies are considered for each component and device of the artificial setup as indicated in Table 1. In the table, a “visually detectable anomaly” is an anomaly that can be detected by watching the device. An “auditory detectable anomaly” is an anomaly that can be detected by listening to the sound from the device. The anomaly of small crack is simulated by putting a seal on the surface of a device. An example small crack is shown in Fig. 3.

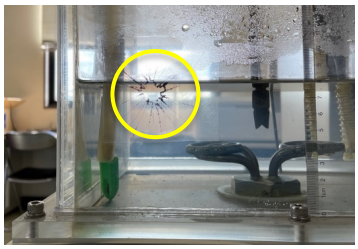

Figure 3 An example small crack on the simulated boiler in the semi-scale experimental plant by a seal (surrounded by a yellow circle).

Table 1 Anomalies considered in artificial setup

Device	Visually detectable anomaly	Auditory detectable anomaly
Power supply unit	1. Small crack 2. Not putting on	1. Abnormal small sound
Liquid crystal display	1. Small crack 2. Small crack on screen 3. Small crack on a meter displayed on screen 3. Display program is halted	1. Abnormal small sound
Semi-scale experimental plant	1. Low water level and not mixing 2. Small water leak 3. Small crack on the front of the simulated boiler 4. Small crack on the side of the simulated boiler	1. Abnormal small sound
Oscilloscope	1. Small crack 2. One of two lines is not displayed	

2.3. Data acquisition methods

The performance of a patrol inspection is evaluated by the detection rate of anomalies. For the record of a patrol inspection, a report sheet is prepared to report the indicated values corresponding to the operating conditions of components/devices and anomalies found.

In this study, the differences of inspection behavior are also analyzed by the places and periods of eye fixation during patrol inspections. The eye fixation points are measured using an eye-ball measurement device (Takei-kiki, TalkEye Lite). The component/device that a participant looks at is analyzed by the images taken by a camera of the eye-ball measurement device and the eye fixation point measured by the device. An image analysis software Yolo [Redmon, 2016] is applied in the analysis. In a preliminary analysis by the authors, the average accuracy of automatic detection of the component/device that a participant looks at is 92 %.

In addition, a questionnaire after the experiment is prepared to confirm if a participant of experiment follows the experimental instruction.

2.4. Indices representing the performance of patrol inspection

In order to evaluate the effect of patrol inspection strategy, the indices to represent the performance of patrol inspection are necessary. The performance of a patrol inspection is directly evaluated by the detection rate of anomalies. The efficiency of anomaly detection is also important because the time for a patrol inspection is usually limited. One of the indices to express the efficiency of anomaly detection can be anomaly detection rate per unit eye fixation period because some kinds of anomalies can be detected visually. Note that the eye fixation period includes the reading of indicators of the artificial setup.

2.5. Experimental procedure

Fifteen healthy students of engineering departments participate in the experiments.

The procedure of the experiment is as follows:

1. explanation of the outline of the experiment,
2. signing the agreement of participation,
3. confirmation that the participant has no healthy problem to wear eye ball measurement device,
4. patrol inspections of the artificial setup in normal operating condition for two times,
5. wearing eye ball measurement device and its calibration,
6. patrol inspection in normal operating condition for one more time,
7. setting some anomalies,
8. instruction of patrol inspection and conducting patrol inspection,
9. repeat steps 7 and 8 for more two times,
10. questionnaire after the experiment.

The participant is asked to submit the report sheet after each patrol inspection task. Five participants (Group 1) are not instructed any patrol inspection strategy. Five participants (Group 2) are instructed to follow visual strategy, and remaining five participants (Group 3) are instructed to follow auditory strategy.

3. Results of Experiment

The data obtained from the experiment are videos of field of view by the camera and eye fixation data by the eye ball measurement device, filled report sheet for each patrol inspection, and answers of the questionnaire after conducting patrol inspection tasks.

3.1. Detection rate of anomalies

Table 2 shows the detection rate of anomalies for each participant. The same anomalies are set for each participant. Totally 19 visually detectable anomalies and 6 auditory detectable anomalies happen in the three patrol inspection tasks with happening of the anomalies. The detection rates for each visually detectable anomaly are shown in Fig. 4. On the other hand, the rates for each auditory detectable anomaly are shown in Fig. 5.

Table 2 Detection rate of anomaly for each participant

Partici-pant	Strategy	Visually detectable anomaly		Auditory detectable anomaly	
		Detection	Detection rate (%)	Detection	Detection rate (%)
A	No instruct-ion	10	52.6	1	16.7
B		15	79.0	2	33.3
C		6	31.6	2	33.3
D		10	52.6	3	50.0
E		11	57.9	2	33.3
F	Visual strategy	13	68.4	5	83.3
G		9	47.4	5	83.3
H		13	68.4	0	0.0
I		18	94.7	6	100.0
J		15	79.0	3	50.0
K	Auditory strategy	7	36.8	4	66.7
L		7	36.8	5	50.0
M		17	89.5	6	100.0
N		12	63.2	3	50.0
O		6	31.6	4	66.7

The rate with visual strategy seems to be higher for the visually detectable anomalies with low detection rates such as the crack in power supply unit, the halted display program in crystal display, and the crack on the front of the semi-scale experimental plant although detection rates are almost the same independent on the anomalies with high detection rates.

The anomaly detection rates for auditory detectable anomaly of small abnormal sound by no strategy are low compared with the cases having visual or auditory patrol inspection strategy. In addition, the rates tend to become higher by having auditory patrol inspection strategy.

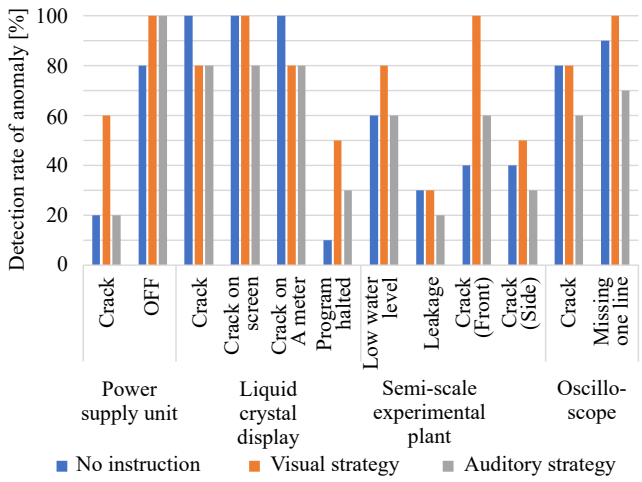

Figure 4 Anomaly detection rates for visually detectable anomalies.

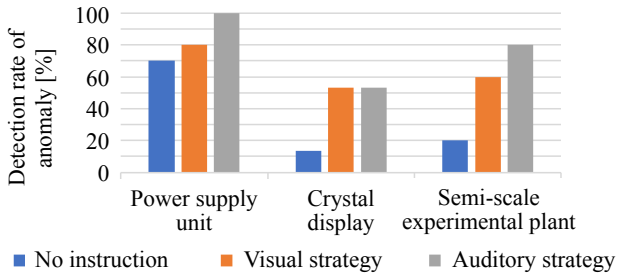

Figure 5 Anomaly detection rates for auditory detectable anomalies.

3.2. Eye fixation periods

The total eye fixation period of each participant is shown in Table 3. Figure 6 shows the average total eye fixation period on each component of the artificial setup.

Although, the difference of eye fixation periods among the patrol inspection strategies is not clear, the eye fixation period with visual strategy tends to be longer than those with other two patrol inspection strategies.

Table 3 Total eye fixation periods of participants

Strategy	Total eye fixation period [s]				
No instruction	133.1	68.1	146.9	91.7	89.1
Visual strategy	106.7	68.7	83.5	259.4	118.4
Auditory strategy	80.2	61.7	235.9	104.3	65.7

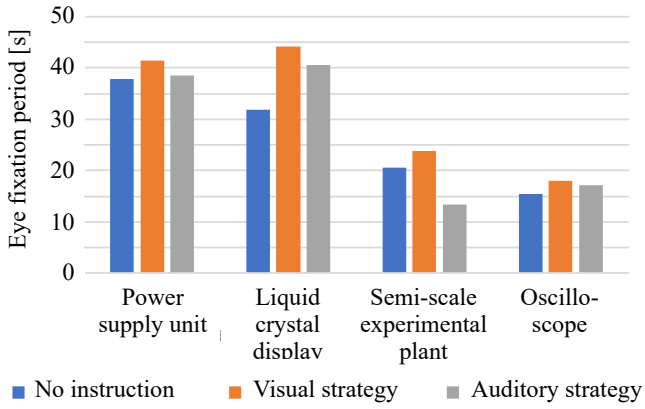

Figure 6 Average eye fixation periods on components.

3.3. Anomaly detection rates per unit eye fixation period

The anomaly detection rates per unit eye fixation period for three types of patrol inspection strategies are compared. The rates for each visually detectable anomaly are shown in Fig. 7. On the other hand, the rates for each auditory detectable anomaly are shown in Fig. 8.

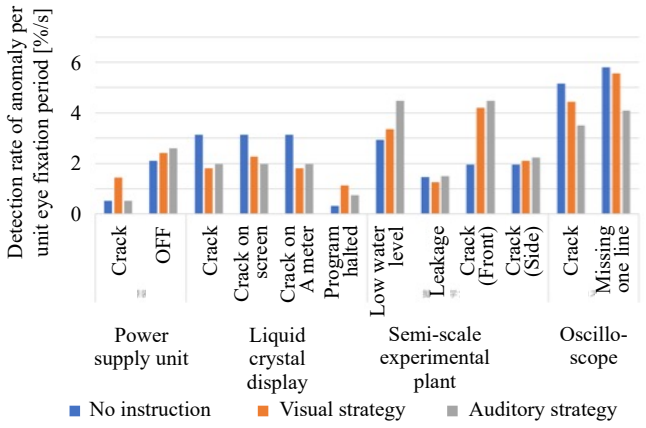

Figure 7 Anomaly detection rates per unit eye fixation period for visually detectable anomalies.

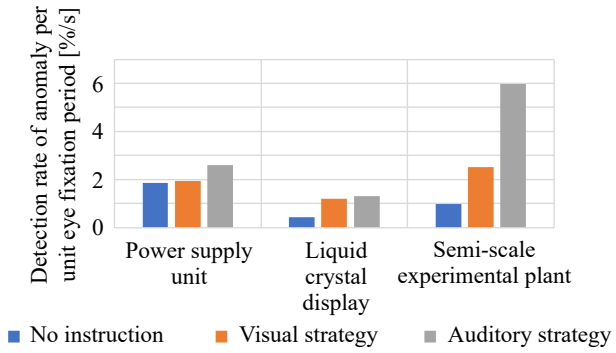

Figure 8 Anomaly detection rates per unit eye fixation period for auditory detectable anomalies.

The rate with visual strategy seems to be higher for the visually detectable anomalies of low detection rates per unit fixation period such as the crack in power supply unit and the halted display program in crystal display although the rates are almost the same independent on patrol inspection strategy for the anomalies of high detection rates per unit fixation period.

As to the anomaly detection rates per unit eye fixation period for auditory detectable anomalies, the rates for abnormal small sounds of the crystal display and semi-scale experimental plant are much higher by having patrol inspection strategy. In addition, the detection rates tend to become higher by having auditory strategy.

4. Discussions

From the experimental results, patrol inspection with visual or auditory strategy tends to give higher rates of detecting anomalies especially for the anomalies that are difficult to detect. The result suggests positive effect of being conscious of one modality on another modality. The effect seems to be stronger by having auditory strategy because the anomaly detection rates for visually detectable anomalies are almost the same in the cases of having visual strategy and auditory strategy but the detection rates for auditory detectable anomalies by auditory strategy are higher than those by visual strategy. This may be because human behaves based on the information obtained visually compared with that by auditory sensation.

5. Conclusion

This study experimentally examined the effect to the detection rate of anomalies in patrol inspection by being conscious of the possibility of a visual or an auditory abnormality. A simulated small plant using the devices that are similar to plant components was constructed as a site for patrol inspections. Two types of patrol inspection strategies were examined: visual strategy that focuses on watching component conditions and auditory strategy that focuses on listening abnormal sounds.

The experimental results are summarized as follows. The visual strategy had some positive effect in the detection rate for visually detectable anomalies. The auditory strategy was suggested to improve the detection rates for auditory detectable anomalies and to have some positive effect for the detection rates for visually detectable anomalies.

Future works include to increase the number of participants of experiments to confirm the tendency obtained in this study by statistic analyses. In addition, the detection performance depending on the patrol inspection strategies is necessary to be compared by controlling the level of difficulty of anomaly detection for further investigation of the effect of having patrol inspection strategies.

References

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