Journal of Engineering and Applied Sciences 6 (4): 237-241, 2011
ISSN: 1816-949X
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Systematic Search for Visual Inspection on a 3-Dimensional Simulation Model

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Abstract: Visual inspection is a crucial process in industrial quality control. Visual inspection primarily relies on the inspector's performance which can be influenced by many factors. The purpose of this study is to identify, the most suitable search pattern and training pattern for visual inspection of a 3D simulation model. The program was set to create a 3D task to measure the visual inspection search patterns. The sampling group was screened for performance and efficiency, 48 students were selected for the experiment and were divided into two groups a systematic rotation pattern group and a free rotation pattern group, respectively. The results showed that the search pattern that produced the best performance from the inspector for visual inspection of a 3D simulation model was systematic horizontal search with systematic rotation.

Key words: Quality control, training, visual inspection, 3D, simulation model, systematic rotation, search patterns

INTRODUCTION

Quality control has become crucial for industrial manufacturing because industry is highly competitive (Chatterjee *et al*., 2002; Friedman, 2006). Industry requires quality control and effective inspection, every organisation should be well prepared and adaptive in order to meet customer demand and satisfaction (Kelly, 2008). A major factor that drives an organisation's success is the product quality (Paquin *et al*., 2000; Gollomp, 2008) in relation to the product standard. Quality control is a means to create a qualified product to deliver to customers. Therefore, it can be said that inspection is an important step in the industrial manufacturing process because it reduces the number of defective products delivered to customers. An inspector is an important person who is responsible for the inspection and must be trained in the proper inspection techniques in order to perform the fastest and most effective inspection. Inspection can take many forms such as a visual search, a measurement or a which are all governed by a standard. Visual inspection is the process for searching for defects within the assigned area by relying on two main components; human visual search and decision making (Thapa *et al*., 1996). It is easy to perform and is thus widely used in industrial factories. Visual inspection is primarily based on a human inspector's performance in identifying defects during the inspection task and on decision making about whether to accept the defect spotted. The two important factors for visual inspection are the speed and the accuracy of the inspection (Jiang *et al*., 2003). For the most part, visual inspection and its search patterns involve identifying defects and making decisions about defect acceptance. Improper search patterns, either in defect searches or in rotation patterns could lead to lower inspector performance in terms of search speed as determined by the search time and the accuracy rate of defect detection (Baker *et al*., 1960). Generally, visual inspection is based on the eye movements of three search patterns: horizontal search, vertical search and random search. Moreover, the rotation pattern is another factor that affects the search accuracy and time. Generally, there are two types of rotation patterns; systematic rotation and free rotation. The characteristics of the defect search can be categorised into three types: 2 and 3D search and virtual search. Each search type has different pros and cons. The 1st type of search, 2D search is a limited search type in which objects or tasks cannot be fully seen and inspected. For example, 2D search has been used on a computer (Jiang *et al*., 2003, 2004) to display the image of a Printed Circuit Board (PCB) or the design on cloth in the textile industry (Kumar,

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2008). The 2nd type of search, 3D is a model simulation for defect inspection in which the tasks are more similar to the real tasks. This approach can help the inspectors become familiar with the defect search process and help them cover a wider inspection area. The final type of search, virtual is a model simulation in which the tasks are most similar to the real ones. However, advanced technology is required to create the simulation.

Although, virtual search has the best quality, its cost is high because of the required special equipment. Therefore, the most suitable search type for factories is 3D which suits the factories in developing countries well because of its reasonable price compared with its efficiency at providing a search that is almost the same as the actual inspection. At present, computer technology has been adopted as a helpful tool for employee training (George *et al*., 2003) to simulate a situation in which the trainees can gain an experience similar to the real one, especially in terms of the factory's quality control operations.

The adoption of computers can help provide more convenience in training for large number of trainees can reduce the amount of time needed for training and can reduce the cost of damage that can occur during an inspection.

From the above rotation pattern and search pattern factors that affect the inspector's performance either in terms of time or accuracy (Megaw, 1979), a proper pattern should be identified to provide higher performance to the inspectors. Besides, visual inspection is the fastest and the best cost-saving tool that also provides the highest performance.

Using a computer program to assist the inspection by simulating a search can help save the organisation's time and costs while also providing expertise in defect inspection to inspectors before they perform real work, resulting in a higher level of performance from the employee. Therefore, this study was conducted for the purpose of exploring the search and rotation patterns used on a 3D simulation model to identify the most effective search pattern. There are three types of search patterns; horizontal search, vertical search and random search.

MATERIALS AND METHODS

To identify the most effective search pattern, an analysis comparing the variance of >2 variables was conducted by a statistical analysis program. This experiment was a factorial experiment with a 2×2 factorial design and it was conducted with two groups with three patterns of subjects who met the selection criteria and who were equally separated into groups by a random drawing. The implementation plan for the search pattern study is shown in Table 1.

Subjects: The subject groups were undergraduate students from the Department of Industrial Education, Faculty of Industrial Education and Technology, King Mongkut's University of Technology, Thonburi, Thailand. The sampling group consisted of 48 normally sighted students who could detect >50% of the faults and who spent <50% of the time on all of the tests (Watanapa and Kaewkuekool, 2007).

Instruments: Computers that supported the visual search simulation program were used in the experiment. The computer specifications were as follows: OS-Microsoft Window XP professional, processor-core 2, monitor 42 inch Duo T9600 LCD TV, keyboard-standard keyboard and mouse-standard mouse. The simulation program is shown in Fig. 1. The program for visual search simulation adopted in the experiment was designed and set to simulate the task in 3D and to have Roman letters as defects for the search as well as the background as shown in Fig. 2. A web camera was used to observe and record the subjects' eye movements during the inspection process. The letters used to represent defects and the

Table 1: Implementation plan for the search pattern study

Search method	Systematic rotation (A)	Free rotation (B)
Horizontal (1)	1A	1B
Vertical (2)	2A	2B
Random (3)	3A	3B

1A: Vertical inspection through systematic rotation; 2A: Horizontal inspection through systematic rotation; 3A: Random inspection through systematic rotation; 1B: Horizontal inspection through free rotation; 2B: Vertical inspection through free rotation and 3B: Random inspection through free rotation

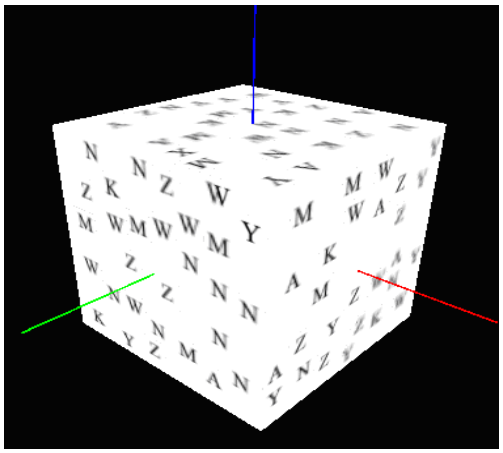

Fig. 1: 3D simulation program for the experiment

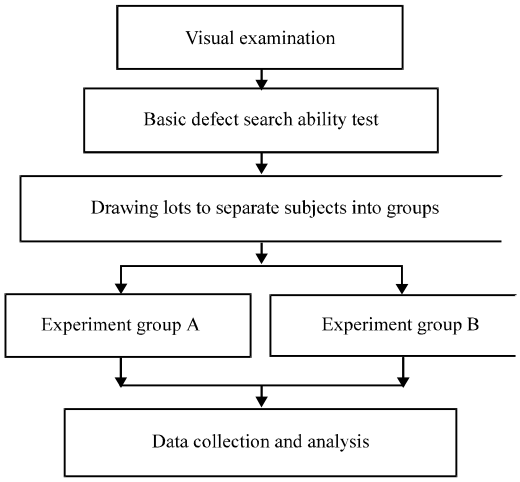

Fig. 2: Step and method for the search pattern used on the 3D simulation model

letters used for background were black and were the same size. All of these black letters appeared on a white screen for the 3D simulation model because previous studies have shown that black letters on a white screen provide the most contrast in colours and are the most obvious (Bix *et al*., 2003; Watanapa *et al*., 2011).

RESULTS AND DISCUSSION

The results of the search pattern used for visual inspection of a 3D simulation model are shown in Table 1, 48 subjects who met the selection criteria were randomly divided into two groups of 24 people each by the lot method. The results for the average search time and the average percentage of search accuracy for each groups are shown in Table 2 and 3, respectively.

An analysis of variance of the average search time shown in Table 4 and the average percentage of search accuracy shown in Table 5 were conducted for the defect inspection test with the two groups by comparing average search time and average percentage of search accuracy as a function of search pattern and rotation pattern.

Table 4 shows an analysis of variance comparing the different average search times, it shows that there is no correlation between search pattern and rotation pattern. When comparing only the search pattern factor, average search time was not different. However, comparing only the rotation pattern factor showed that average search time was significantly different at the level of 0.01. Table 5 shows that an analysis of variance comparing the difference between average percentage of search accuracy among the subjects showed no correlation

Table 2: Results of average and standard error of mean for search time

Search methods	Axis-based rotation (sec)	Free rotation (sec)	Average time (sec)
	$\bar{X} \pm SE$		
Horizontal	516.60±63.39	715.29±47.67	615.94±46.11
Vertical	532.36±52.11	743.08±48.41	637.72±43.82
Random	580.38±40.99	772.59±54.59	676.48±41.27
Average time	543.11±29.76	743.65±28.19	643.39±25.00

Table 3: Results of percentage of accuracy and standard error of mean

Search methods	Axis-based rotation	Free rotation	Average time
	$\bar{X} \pm SE$		
Horizontal	94.00±2.93	75.50±4.54	84.75±3.54
Vertical	85.88±3.72	79.50±6.10	82.69±3.55
Random	85.88±3.72	77.50±5.43	81.69±3.36
Average time	88.58±2.08	77.50±3.00	83.04±1.98

Table 4: ANOVA result of search time

Sources	Type III sum of squares	df	Mean square	F-test	Sig.
Corrected model	513391.282 (a)	5	102678.256	4.810	0.001
Intercept	19869182.850	1	19869182.850	930.759	0.000
Rotation pattern	482593.494	1	482593.494	22.607	0.000
Search pattern	30091.800	2	15045.900	0.705	0.500
Rotation search*	705.988	2	352.994	0.017	0.984
Error	896586.476	42	21347.297	-	-
Total	21279160.608	48	-	-	-
Corrected total	1409977.758	47	-	-	-

Table 5: ANOVA result of search accuracy

Sources	Type III sum of squares	df	Mean square	F-test	Sig.
Corrected model	1890.167 (a)	5	378.033	2.295	0.062
Intercept	331004.083	1	331004.083	2009.638	0.000
Rotation pattern	1474.083	1	1474.083	8.950	0.005
Search pattern	78.042	2	39.021	0.237	0.790
Rotation search*	338.042	2	169.021	1.026	0.367
Error	6917.750	42	164.708	-	-
Total	339812.000	48	-	-	-
Corrected total	8807.917	47	-	-	-

Table 6: Comparison between two patterns of rotation

Rotation patterns	Systematic rotation	Free rotation
Systematic rotation		*
Free rotation		

*Refers to different average search time at significant level of 0.01

between search pattern and rotation pattern. Moreover, there was no difference in search accuracy within the search pattern factor. On the contrary, the comparison within the rotation pattern factor showed that average search time was significantly different at the level of 0.05. For the analysis between average search time and average percentage of search accuracy, it was found that rotation pattern was the factor that affected average search time and average percentage of search accuracy. Therefore, a paired comparison analysis was launched to find the difference between subfactors by using the Least Significant Difference (LSD) which yielded the results shown in Table 6 and 7. Table 6 shows the average search time for systematic rotation differs from the

Table 7: Comparison between average percent of search accuracy based on two rotation patterns

Rotation patterns	Systematic rotation	Free rotation
Systematic rotation		**
Free rotation		

*Refers to different average search time at significant level of 0.05

Table 8: Comparison between search time and percentage of accuracy (visual search performance) based on two rotation patterns

Rotation patterns	Search time (sec)	Search accuracy (%)
Systematic rotation	543.11±29.76	88.58±2.07
Free rotation	743.65±28.19	77.50±2.99

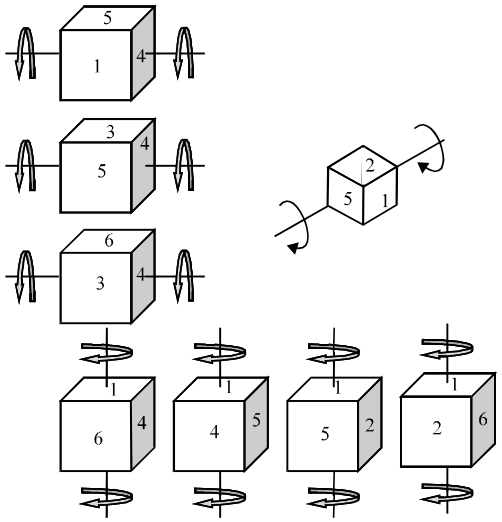

Fig. 3: The most effective rotation pattern started with horizontal rotation

average search time for free rotation at the significance level of 0.01. From Table 7, the average percentage of search accuracy based on systematic rotation is different from the average percentage of search accuracy based on free rotation at the significance level of 0.05. In order to find, the most effective search pattern for visual inspection of a 3D simulation model, the two factors search pattern and rotation pattern were studied by analysing the performance of the subjects based on average search time and average percentage of search accuracy as well as by analysing search pattern from the movement recorded during the experiment and from the interview. The test was conducted under the implementation plan (Fig. 2) with 48 subjects to identify the most effective search pattern; the results are shown in Table 8. An analysis of search pattern from the recorded movement and from the interview showed that the systematic rotation that yielded the highest performance could be broken down into two different approaches. The 1st approach started with horizontal rotation, moving clockwise to each of the four search areas before using vertical rotation in two areas as shown in Fig. 3. The 2nd

Table 9: Comparison between search time and percentage of accuracy (visual search performance) based on three search patterns

Rotation patterns	Search time (sec)	Search accuracy (%)
Horizontal search	615.94±46.11	84.75±3.54
Vertical search	637.72±43.82	82.69±3.55
Random search	676.48±41.27	81.69±3.36

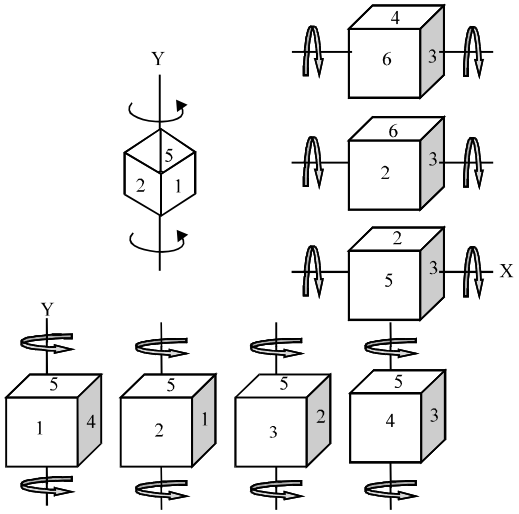

Fig. 4: The most effective rotation pattern started with vertical rotation

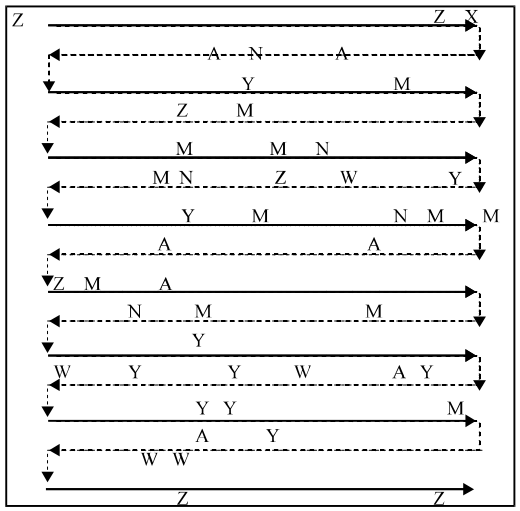

Fig. 5: The horizontal search pattern is the most effective pattern

approach started with vertical rotation, moving counter clockwise to each of the four search areas before using horizontal rotation in two areas as shown in Fig. 4. The results from the analysis of variance are shown in Table 6 and 7 together the comparison between average search time and average percentage of search accuracy based on three search patterns. Table 9 shows that all three search patterns had no effect on average search time

and average percentage of search accuracy. However, when specifically considering the overall mean shown in Table 9, the horizontal search provided the least search time and the highest average percentage of search accuracy. Moreover, according to the analysis of search pattern from the recorded movement and the interview with the subjects, the horizontal search used by the subjects started with the top of the search area. Then, the eye moved horizontally from left to right down to the bottom as shown in Fig. 5 (Mao-Jiun *et al*., 1997; Drury, 1984). This was the most effective search pattern.

CONCLUSION

The results of this study revealed that rotation pattern and search pattern are the two factors related to 3D simulation models that had the largest effects on the visual inspector's performance in terms of search time and percentage of search accuracy.

For the rotation pattern, systematic rotation provided more effective inspection performance than free rotation because the systematic rotation has an obviously organised pattern as shown in Fig. 3 and 4, resulting in a reduction in the duplicated search area. The full area could be searched quickly in less than the time allotted with increased search accuracy.

For search pattern, the horizontal search with systematic rotation was the most effective of all of the search patterns because it used a systematic method that covered the total area and that conformed to the search pattern theory that states that systematic searching with eye movements from left to right or top to bottom provides the most accurate and fastest inspection. According to the study, the training provided to the inspectors helped increase their performance. They demonstrated high search accuracy at faster speeds because they had been given instructions that helped in decision making about targets and which reduced mistakes. Thus, providing information through training is a means to increase a visual inspector's performance. The level of performance can be further enhanced by providing feedback after each inspection.

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