ANALYSIS OF THE *GAZE BEHAVIOUR* OF THE WORKER ON THE CARBURETOR ASSEMBLY TASK

Novie Susanto[*)]

Industrial Engineering Study Program, Faculty of Engineering, DiponegoroUniversitas
Jl. Prof. Soedharto, SH, Kampus Undip Tembalang, Semarang Indonesia 50275

Abstract

This study presents analysis of the area of interest (AOI) and the gaze behavior of human during assembly task. This study aims at investigating the human behavior in detail using an eye-tracking system during assembly task using LEGO brick and an actual manufactured product, a carburetor. An analysis using heat map data based on the recorded videos from the eye-tracking system is taken into account to examine and investigate the gaze behavior of human. The results of this study show that the carburetor assembly requires more attention than the product made from LEGO bricks. About 50% of the participants experience the necessity to visually inspect the interim state of the work object during the simulation of the assembly sequence on the screen. They also show the tendency to want to be more certain about part fitting in the actual work object.

Keywords*:* *assembly; gaze behaviour; eye tracking system; cognitive*

Introduction

Cognitive engineering has become an important aspect of production systems research. To improve productivity, safety and well-being, it is important to highlight the role of human cognition in future production systems. Most conventional production systems are designed with their focus on advanced technology and a strong emphasis on automation. Design for cognitive compatibility plays a vital role in these complex work systems regarding the improvement of joint performance and optimization in human-machine and human-robot interactions.

A solution is provided through the ergonomic design of human-robot interaction (HRI) with balanced automation. This approach features a high level of robotic automation offering a broad range of advantages (in terms of precision, control and reproducibility), without hindering the human operator in utilizing and developing his or her individual knowledge, skills and abilities. Hence, ergonomic HRI presents the most advantageous option for maintaining productivity and increasing flexibility while continuously optimizing and adapting the corresponding manufacturing processes.

To evaluate the effects of automation functions in a work system, the definition of the term "automation" is required. Automation is defined as "automatic control of the manufacture of a product through a number of successive stages; the application of automatic control to any branch of industry or science; by extension, the use of electronic or mechanical devices to replace human labor" (OED, 2010). Referring to the extended definition of automation, "human labor" in automated work systems is not habitually replaced. The role of human operators in highly automated systems is essential, especially to carry out various kinds of supervisory control tasks, or to intervene whenever errors occur (Mayer et al., 2012). Hence, future manufacturing systems should focus on the integration of human operators in the production environment according to his or her specific capabilities in problem solving, decision making and planning (Schlick et al., 2002).

Human workers fulfill an essential role in production systems and feature individual methods, strategies and procedures when carrying out their respective work tasks. In a joint cognitive system, they fulfill a combined role of operator and system supervisor. Therefore, they should be able to effectively make decisions, support the team in the work system and autonomously conduct actions, especially in situations critical to safety or quality. Thus "cognitive patterns", as high-level structures of cognitive control, are critical points in these work systems because a large part of system performance is dependent on human cognition. This human-oriented symbolic representation is used as a basis of cognitive planning and control system design. Conventional research in ergonomics often treats participant cognition as a static factor within the system. This conventional approach contradicts the user-centered design of human-robot systems where participants experience a change in cognitive processes through their contextualized learning experience with the robot(s). Changes in cognitive processes reflect the

[*)] Penulis Korespondensi.
email: nophie_susanto@yahoo.com.sg

adaptation of the participants' mental model in the human-robot system and the participants' understanding of broader concepts within robotics.

To ensure conformity of the operator's expectations with the technical system during the supervision of robotic assembly processes (Mayer et al., 2008), the first step in the design process is to use motion descriptors of the hand-arm system for planning and executing the assembly steps within the Cognitive Control Unit (CCU). A cognitive control unit (CCU) is designed based on an architecture of human cognition. It has been developed to achieve a better compatibility between the human mental model and the knowledge base of the robot. A CCU is assigned the coordination of seemingly non-value-adding tasks (i.e. low-level control programming) are transferred from high-expertise workers to the robot. By doing so, the CCU can reduce the burden of repetitive, simple, and dangerous tasks on human operators. It allows the rule-based processing of events in a production system (Mayer et al., 2009; Buescher et al., 2012). The CCU can also autonomously plan assembly processes and react effectively to ad hoc changes, based on a self-developed set of production rules within its knowledge base. This means that rule-based human behavior can be simulated leading to self-optimizing assembly processes (Mayer et al., 2011).

This study design is based on premise that the repetitive motions of hands and arms are familiar to the human operator through training in manually performed assembly tasks (Gazzola et al., 2007). When processing a supervisory task, however, the human operator is continually monitoring the activities in the system, and comparing them with his/her mental model. Based on the human mental model, expectations for the following activities can be formulated and compared to observations of the system state. When the knowledge base of the CCU is extended by integrating production rules based on human heuristics, the robot's build-up sequence can be better anticipated by the human operator. Moreover, it is more compatible with his/her procedural knowledge of the assembly process and leads to less errors and lower levels of stress (Mayer and Schlick, 2012). Mayer (2012) carried out a laboratory study to verify the predictability of robot behavior when assembling plastic LEGO bricks. This empirical study took human assembly strategies into account. Here, work regarding the predictability of robot behavior and the development of the human-machine interface represent the foundation for this study. The study objective is to evaluate human behavior in detail using an eye-tracking system during assembly task using LEGO brick and an actual manufactured product, a carburetor. An analysis using heat map data based on the recorded videos from the eye-tracking system is taken into account to examine and investigate the gaze behavior of human.

The eye-tracking system is typically used to analyze the human behavior when he/she interact with other human, machine or other supporting work equipment. Evaluation of the eye-tracking system in ASD patients can be found in the Damm et al. (2013). Within this study, it is resulted that ASD patients potentially maintain eye contact during interaction with the social robot as compared to the human actor. Specifically in human-robot interaction, a demonstration of the importance of using physiological measures is resulted (Carlson and Demiris, 2009). An important result was found regarding the existence of an adaptive assistance. The result was detected as counter-intuitive with the initial hypothesis; for example, it has been expected that the user would require less visual attention for driving, whilst they are being assisted by the collaborative system. By doing so, it allows them to concentrate on higher level of cognitive tasks, such as planning or performing a visual search. However, the result leads on different way. The pattern of saccadic activation increase and become more chaotic under the assisted mode especially for untrained user. This result should be considered as a factor in designing an ergonomic human-robot interaction.

Based on the results of previous study, it has been found that an eye-tracking system can be very useful to verify whether the designed system is fulfilling user requirements regarding eye attention. However, the previous studies were not pay attention on the importance of the interaction between human operator and the technical system in detail during the work. In this study, the human operator attention during the work as well as during the interaction with the technical system or robot should be taken into account. It aims at improving the human operator conformity and the safety of the work system.

Methods

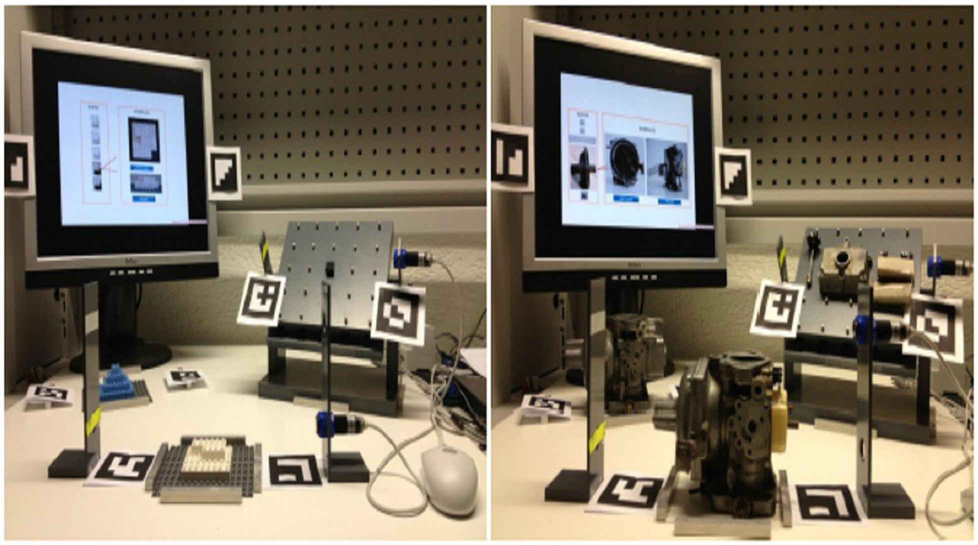
Apparatus

This study uses a 28" TFT screen to visualize the assembly sequence. There is an area for assembly work in front of the participant and an area for putting the completed product, as well as a table for the part that is used for the prediction task. Figure 1 shows the main component used in this study.

An eye-tracking system is utilized in this study to acquire gaze behavior and Area of Interest (AOI) data. The data is obtained using a head unit eye-tracking system that records the participants' eye pupil movement when conducting and completing the study task. The head unit consists of an EyeCam to capture a high quality black and white video of the eye during the course of an experiment as well as a FieldCam to capture a high quality color of the field of vision of the subject. The video data recorded by the cams in the head unit are transmitted to the electronic unit in real time. The video data captures the area of interest of the subject during the study. This is shown by the recorded eye pupil movement of the working area and a heat map analysis. Figure 2 shows a different view on the experimental environment, in which the participant wears an eye-tracking system.

The study is conducted with 13 participants from Indonesia (range of ages 28.5 ± 4.7 years old), which coincides with the prediction study (see Susanto et al, 2014 for the further detail).

The eye-tracking system considers four area of interest (AOI) in its environment. AOI 1 concerns the screen for assembly guidance visualization. AOI 2 covers the predicted LEGO brick or carburetor part. AOI 3 encompasses the assembly work area, while AOI 4 is designed to track eye activity in the completed assembly group area. Figure 3 presents the AOI in this study.



(a) (b)

Figure 1. Environment of the study (a) for the product made from LEGO bricks (b) for the carburetor

Figure 2. Environment of the study with the eye-tracking system

Figure 3. The areas of interest in this study

Procedure

The procedure of this study 2 is divided into three main phases:

(1) Personal data collection and training under study conditions
First is the anonymized collection of personal data (e.g., age, education level, prior experience with the assembly task and LEGO assembly). The participant is introduced to the apparatus, the study environment the interim state and the completed object assembly group after the personal data are collected.

(2) Calibration of the eye-tracking system
Secondly, the calibration of the eye-tracking system is performed through the following procedures:
- Placing the head unit of the eye-tracking system on the participant's head.
- Starting the Dikablis recorder program and initiating eye detection.
- Calibrating the optical tracers based on standard areas.

(3) Data acquisition
The next phase consists of illustration and explanation of the assembly task to the participant. These explanations are visible on the monitor. After this, the participant is expected to notice the assembly pattern regarding the sequence of the LEGO brick or carburetor part placement and predict the next position of the LEGO brick or carburetor part. After the prediction task, the participants should examine some assessments that visualized in monitor.

In total, there are 12 prediction tasks divided into two sessions (6 tasks for first session using LEGO brick and 6 tasks for the second session for carburetor assembly) with a randomized order of assembly sequences. The duration per study is approximately 60 minutes for each person including personal data collection, eye-tracking system calibration and performing the required tasks.

Result and Discussion

Area of Interest (AOI)

The eye-tracking system was used to examine the area of interest (AOI) during the execution of assembly tasks. As shown in Figure 3, there are four AOI in Study 2. The data of fixation duration is obtained from the recorded video files based on the eye pupil movement and heat map analysis using D-Lab Analysis software. Figures 4 and 5 show a heat map analysis of the assembly of the product made from LEGO bricks and the carburetor respectively.

Gaze Behavior

The gaze behavior data is analyzed with respect to the working area in the recorded video files. The participants followed a similar pattern regarding gaze behavior during this study, as shown in Figure 6.

Participants generally start to focus on AOI 1 that visualizes the assembly sequences. After the simulation is finished, participants switch to the AOI into the part area (AOI 2). Attention is then shifted to AOI 3, which is the assembly work area. Afterwards, the participants return to AOI 1 to complete the subjective evaluation of the task. There is only a low attention focus from participants on AOI 4. However, during this study, there are also different gaze behaviors, as shown in Table 1.

According to Table 1, the carburetor assembly requires more attention in AOI 3 than the product made from LEGO bricks. About 50% of the participants experience the necessity to check the interim state of the work object during the simulation of the assembly sequence on the screen. The frequency of attention shifting from AOI 1 to AOI 3 during the visualization varies between one and up to four times. Participants tend to ensure the equivalency of the actual work object with the simulated object on the screen. This fact is concomitant with Nisbett and Norenzayan (2002) regarding the cognitive processes of Easterners. In this study, participants tend to pay attention to the relationship between the actual work object and the visualized object on the screen.

The difference of gaze behavior type, as shown in fifth gaze behavior in Table 1, is indicated when the presentation of assembly sequence is finished, and the participants are expected to determine the next assembly part. The participants have less confidence in making decisions about the selection of the next part. They require certainty on the selected fitting part for the actual object work. Thus, the participants often shift their attention to AOI 3 before determining the selected part. The discussion of control and confidence levels of the participants during decision making is also in accordance with the findings of Nisbett and Norenzayan (2002) regarding the Easterner behavior.

The practical implementation of this study can be applied on analyzing direct human-robot interaction. Based on the result of this study, it is known that human operator had a tendency to ensure the similarity between the examples visualized in the display with the real product. In direct human-robot interaction, human operator is expected to pay attention on the assembly guidance and the robot behavior in the similar proportion. By doing so, the safety and the performance of the human operator within work process can be improved.

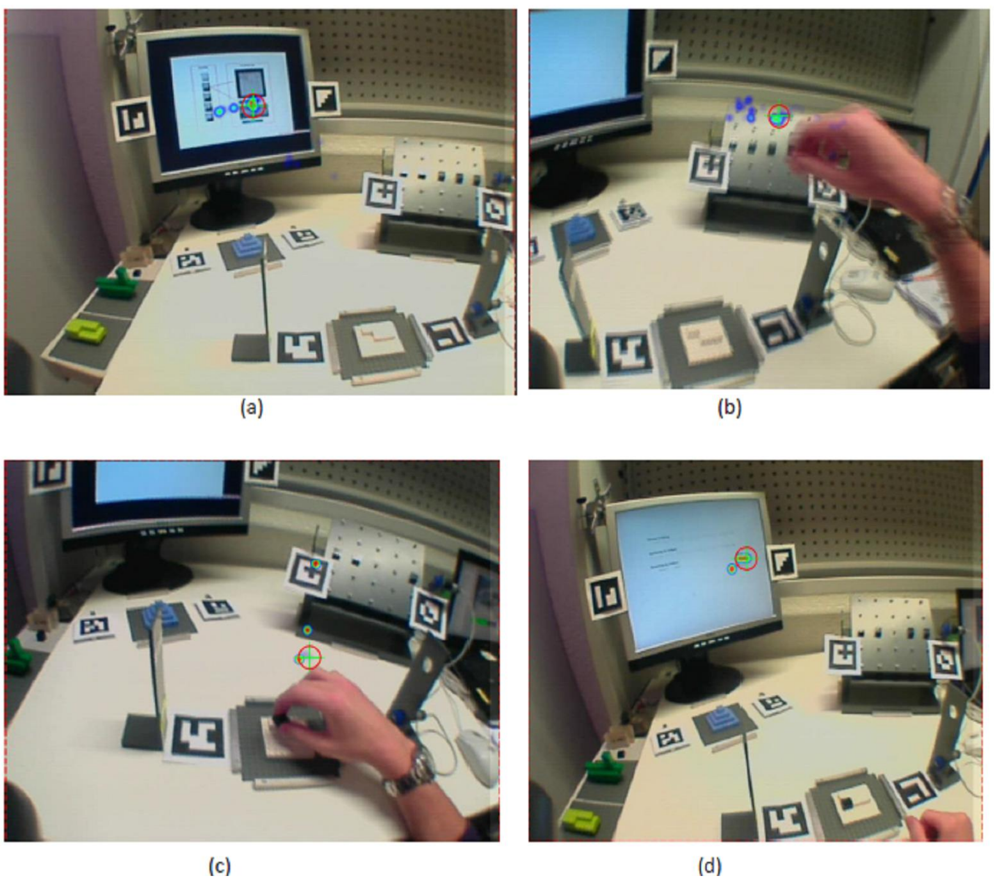


Figure 4. Heat map analysis of AOI 1(a), AOI 2(b), AOI 3(c) and AOI 1 in subjective evaluation (d) of the product made from LEGO bricks

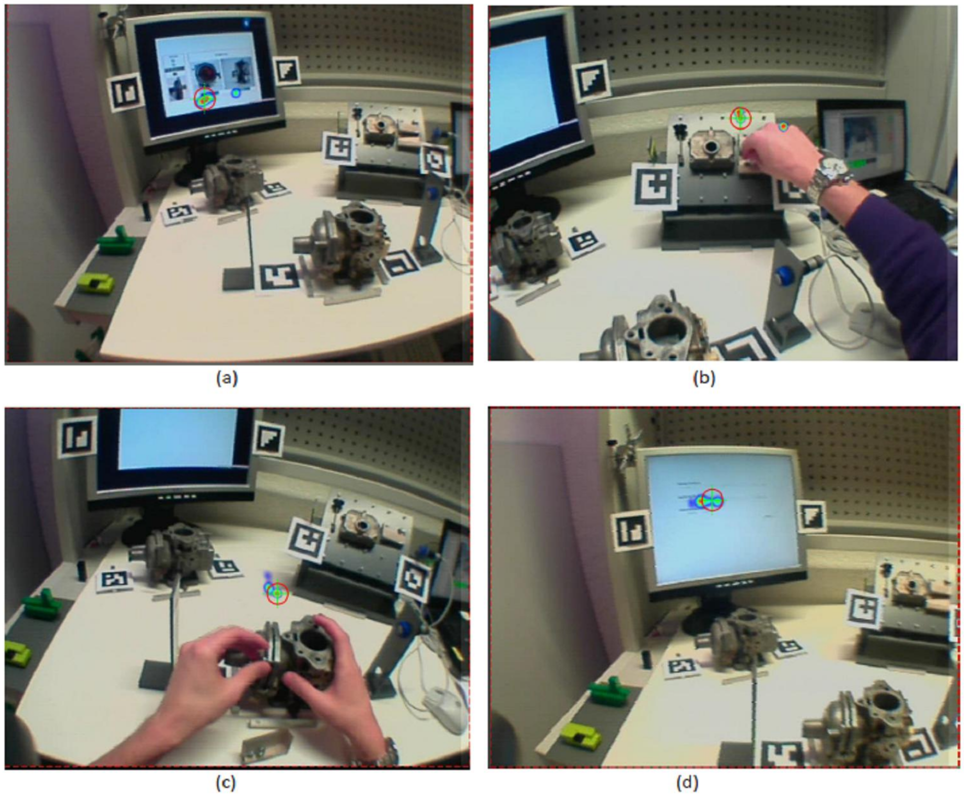


Figure 5. Heat map analysis of AOI 1(a), AOI 2(b), AOI 3(c) and AOI 1 in a subjective evaluation (d) of the carburetor

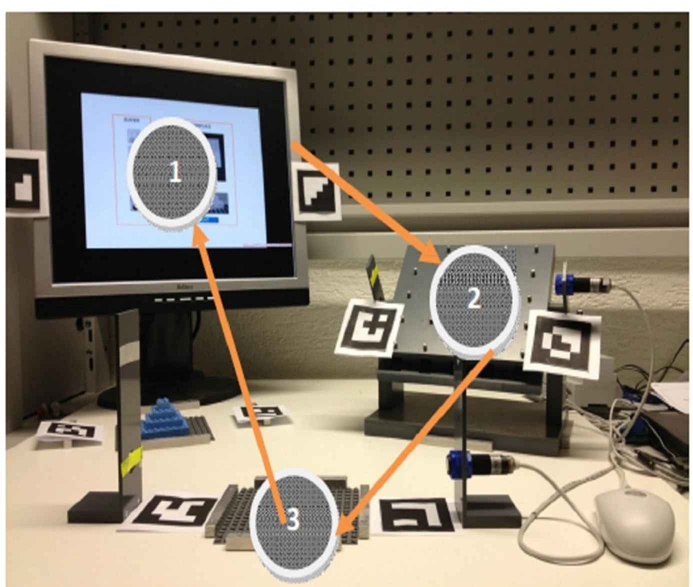


Figure 6. General gaze behavior of participants.

Table 1. Specific style of the gaze behavior based on AOI

Nr.	Gaze behavior based on AOI	Number of participants LEGO	Carburetor
1	1 → 3 → 1 → 2 → 3 → 1	3	6
2	1 → 4 → 1 → 2 → 3 → 1	2	4
3	1 → 3 → 4 → 2 → 3 → 1	0	0
4	1 → 2 → 4 → 3 → 1	1	1
5	1 → 2 → 3 → 2 → 3 → 1	1	6

Conclusion

Based on the analysis of gaze behavior, with regard to AOI 3 we can conclude that the carburetor assembly requires more attention than the product made from LEGO bricks. About 50% of the participants experience the necessity to visually inspect the interim state of the work object during the simulation of the assembly sequence on the screen. The frequency of attention shifting from AOI 1 to AOI 3 varies between one and four times. In spite of the similar number of participants with the gaze behavior according to type 1 (Table 1), the participants exhibit a strong tendency to evaluate the similarity of the actual work object with the simulated object on the screen. In this study, the participants tend to focus on the relationship between the actual work object and the object presented on the screen. They also show the tendency to want to be more certain about part fitting in the actual work object. Thus, the participants pay attention on checking AOI 3 before determining the next part to be assembled.

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