Modeling Cognitive Activities in a Virtual Reality- assisted Industrial Robot Programming Environment

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Abstract

Numerous studies have reported using virtual reality (VR) for training. In these immersive environments, learners were allowed to learn through trial-and-error in order to generate their mental map for specific tasks. Consequently the associated training cost was greatly reduced, and learners were found to perform the desired tasks faster, with fewer mistakes than those trained in traditional ways. Nevertheless, the reported improvement of task speed and accuracy was only summative, without revealing details of the actual learning process.

In this paper we presented an ongoing effort for understanding how individuals navigate in the VR-assisted industrial robot programming environment. A GOMS model is developed via the think- aloud protocol to map out the possible cognitive activities of given tasks. Once completed, this GOMS model may be used to determine an individual's mental map, cognitive load, and detect the misconception during the course.

Introduction

To reduce the cost of training, the use of virtual reality for procedural knowledge inquiry has been reported in various fields (Aggarwal, Black, Hance, Darzi, & Cheshire, 2006; Bliss, Tidwell, & Guest, 1997; Ossmy & Mukamel, 2017). The inquiry of procedural knowledge refers to the learner's internal construction of methods to execute a series of operations to achieve specific goals. According to Card (1981), to perform a procedure, an individual will first perceive the task status via his or her visual, auditory, and haptic sensors, retrieve previous knowledge, compare with the current situation, determine the problem solving strategy, and eventually respond to the external world with the movements. The mastery of the learner can be determined by whether he or she chooses the proper approach and completes the task within the time given without making mission- critical errors.

By immersing the learner in a controlled, computer-simulated environment, the learning outcomes were often better than that in conventional learning settings, as the distractions were reduced or eliminated. Nevertheless, the evaluation of VR-based learning effectiveness was mainly done by measuring individuals' speed and accuracy (Decety & Jeannerod, 1996; Robertson, Czerwinski, & Van Dantzich, 1997). The total number of mistakes made and time needed to complete the task could only depict the difference between the learner's states before and after treatment in a holistic manner. The specific of cognitive activities happened in the VR-based training process was not clear, due to the fact that it was less observable.

Furthermore, in a computer-simulated environment such as VR-assisted training, the learner's cognitive response might vary from the response seen in the physical world (Witmer & Singer, 1998). The human-computer interface (HCI) might provide short cuts to perform specific operations, or the design of the HCI was so awkward that the process becomes very tedious. If a computer- assisted environment is used to evaluate the individual's task performance, his or her familiarity of the HCI has to be considered in order to properly assess the number of error and time used for a task (Bowman, Gabbard, & Hix, 2002).

To address the mentioned concerns, we propose in this paper to model human cognitive activities within the VR setting in order to better understand individuals' task performance. The modeling strategy, GOMS (goals, operators, methods, selection rules) (Kieras, 2004), is used to model an individual's behaviors of performing assigned tasks in a VR-assisted industrial robot programming environment. The main objective is to determine whether individuals' cognitive activities is task-related or HCI-related, thus a more appropriate assessment can be conducted.

Methodology

GOMS, based on Card's human processor model (1981), has been used by researchers in the area of user interface analysis (John & Kieras, 1996). GOMS, the acronym of *Goals*, *Operators*, *Methods*, and *Selection Rules*, is used to describe tasks and corresponding knowledge to perform them. Once created, the GOMS model can be used for developing training tools and help systems. GOMS can also be used to predict human performance. According to John and Kieras, GOMS can be used only if we want to analyze procedural properties of the system. The task needs to be goal- directed and involving user control, and a user can become skilled due to the task's routine nature.

The following is an example of a typical procedural task in the area of industrial robot programming. Prior to creating the robot's tool path, the location of a coordinate system needs to be specified (Devine, 2009). By selecting three points along the edges of a workpiece, the X-Y-Z system can be defined. The sequence of point selection is critical, as it is used to establish the positive Z axis, and consequently the end effector of the robot could approach the workpiece correctly. The GOMS model for such a task can be denoted as Figure 1.

GOAL: CREATE-COORDINATE
. GOAL: CHOOSE-POINT … repeat until all three points selected
. . GOAL: ACQUIRE WORKPIECE … if workpiece exists
. . GOAL: MOVE-CURSOR-TO-EDGE … choose edge
. . GOAL: CHOOSE-POINT-EDGE … choose a point along one edge
. GOAL: VERIFY-Z-DIRECTION … verify if the z axis is in the right direction

Figure 1. Example of GOMS for creating a coordinate system on the workpiece

The above model only shows the procedure to create a coordinate system. It will need to be expanded to include situations such as removing points that are misplaced, or exiting the whole procedure to start all over. It is also beneficial to categorize the cognitive activities based on their commonality. Table 1 illustrates three most common human behaviors when exploring the VR space, namely navigation, inspection, and manipulation.

Table 1. Three common types of cognitive activities within a VR setting: Navigation, Inspection, & Manipulation

Cognitive Activity	Goal	Perceptual Subsystem	Cognitive Subsystem	Motor Subsystem
Navigation	To travel in the virtual space	Orient oneself in the virtual space via visual, auditory, or haptic stimuli	Identify the goal, determine the strategy, and plan the action	Execute the plan via physical or virtual movement in space
Inspection	To determine the state of target systems & propose alternatives	Evaluate the target system via visual, auditory, or haptic stimuli	Diagnose the phenomenon via compare-and-contrast knowledge with external stimuli	Verify the hypothesis by altering the states of the target system
Manipulation	To execute the selected alternatives	Utilize visual, auditory, or haptic sensors to guide the execution	Verify the execution of tasks via visual, auditory, or haptic inputs	Do and adjust movement if necessary

For each category of cognitive activities, a GOMS template will be first created. Next, each task will be represented by a combination of one or more of these cognitive activities. For example, the CREATE-COORDINATE task consists of all three types, navigation (e.g. ACQUIRE- WORKPIECE), inspection (e.g. VERIFY-Z-DIRECTION), and manipulation (e.g. both MOVE- CURSOR-TO-EDGE and CHOOSE-POINT-EDGE).

In addition to the list of tasks, a complete GOMS system measures the time needed for an individual to perform a goal at the lowest level, such as the time needed move the cursor (or pointer in a VR setting) to the edge of workpiece (line 4 in Figure 1). The duration of time in most cases will be a range instead of an exact number, by measuring the expert users' speed. For this purpose, a think-aloud protocol will be utilized for the user to verbally report his or her cognitive states, specifying the goal(s), operator(s), method(s), and selection rule(s).

Current Stage of Research

Figure 2 illustrates the workflow for developing the GOMS model mentioned previously. We are currently developing the GOMS templates for the three cognitive activities mentioned. The critical tasks for the learner to demonstrate mastery will be chosen from the lab material for TEC 234, an introduction course to industrial robot programming. Next these tasks will be modeled with the GOMS templates, and a pilot study with the help of two or three expert users will be conducted to determine the fitness of these GOMS models. After necessary revision, the GOMS task time will be measured by averaging the task time needed by experienced users (those who complete TEC 234 with satisfactory scores), through the utilization of the think-aloud protocol.

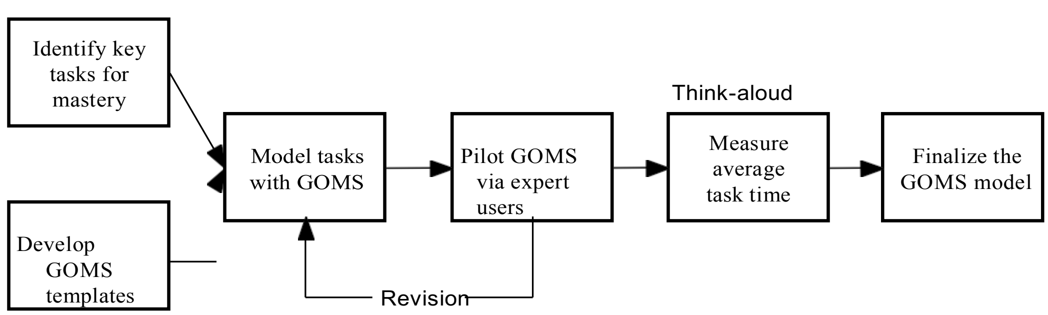

Figure 2. The workflow for developing the proposed GOMS model

Once the GOMS model is created, it can be used to assess the learner's task performance. Because the time needed for each task is presented as a range instead of an exact number, the learner can be considered proficient in a specific cognitive activity, if the time spent by the learner to correctly accomplish the task falls within this given range. The sequence of the operations is another indication whether the learner is on the right track to solve the given task.

Conclusion

An on-going research effort to study the feasibility of an assessment method by modeling a learner's cognitive activities was reported. The need of a different assessment method was identified, and the rationale of using the GOMS model was provided. An example of using GOMS to model the task for industrial robot programming was presented, and the research approach was presented in a flow chart.

By developing GOMS models for tasks in the VR environment, we can detect the lower level performance and determine the learner's level of proficiency. This approach is very promising, as it has been used by multiple HCI researchers to model the user behaviors and study the time needed to complete tasks, such as menu searching, text editing, or button clicking (John & Kieras, 1996). A fully tested GOMS model may also lead to the prediction of learner's performance in the VR environment (Gray, John, & Atwood, 1993; John, 1990), providing suggestion or warning signal to prevent the learner from forming misconceptions and making wrong decisions.

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