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Effects of agent timing on the human-agent team

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Abstract

As technology becomes more sophisticated, autonomous agents are applied more frequently to improve system performance. The current research employed a five step method, including modeling, simulation, and human experimentation to explore the effect of an artificial agent's timing on the performance of a human-agent team within a highly dynamic task environment. Agent timing significantly influenced the role assumed by the human within the team. Further, agent timing changed system performance by approximately 40% within the experimental conditions. Results indicate that an artificial agent's timing can be varied as a function of the task demands placed upon the human-agent team to maintain an appropriate level of human activity and engagement. Therefore, agent timing may be controlled to adapt autonomy to provide an apparent continuum along which to control human engagement in systems employing human-agent teaming within dynamic environments.
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Keywords: Human-agent teaming; Interaction; Timing; Workload

1. Introduction

Although powered machines have been applied to automate difficult, energy-intensive tasks for centuries (Smeaton & De Moura, 1751), the utility of these systems has been limited by their ability to adapt to environmental changes. More recently, systems which adapt to environmental stimuli have been discussed, modeled, and demonstrated (Licklider, 1960; Rouse, 1977). However, these environmentally-adaptive systems typically allocated functions based upon technical feasibility or cost effectiveness. This allocation was thought to be particularly desirable when the machine could perform the function more efficiently, reliably or accurately than the human operator. Thus, the human was left to perform higher level monitoring functions, to detect and correct automation failures, and to perform functions that were difficult to automate due to their complexity (Parasuraman & Riley, 1997). Due to human vigilance loss, mental switching delays, and skill decay, this allocation of responsibility was found to be brittle as machine errors cascaded, resulting in system failure (Wiener & Curry, 1980). In response, the concept of adaptive automation was proposed. In this paradigm, the level of automation changes as a function of human, mission, environment, or system state (Hancock & Chignell, 1988). While adaptive automation changes the allocation of tasks dynamically, both traditional automation and adaptive automation specifically allocate tasks to the

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human or machine. Adaptive automation provides one or more state variables which permit this allocation to change dynamically. However at any one moment in time either the human or the machine is responsible for completion of specific tasks.

Recently, the concept of human-agent teaming has been proposed, in which the human and one or more artificial autonomous agents (1) share goals (Hoc, 2001), (2) are interdependent (Arthur et al., 2005), and (3) dynamically allocate roles (Bruemmer, Marble, & Dudenhoeffer, 2002). In this paradigm, task allocation is not fixed. Unlike systems employing automation, autonomous systems possess the capacity and have the authority to decide which goals they are going to pursue and the tasks they are going to perform to accomplish those goals. Thus, in human-agent teams, both the agent and the human can select which actions to take to achieve a higher level goal.

The concept of human-agent teaming is not new (Rouse, 1981; Rouse, Edwards, & Hammer, 1993; Scerbo, 1996). However, few examples of human-agent teams having all three of these attributes have been discussed in the literature. Further, the existing literature on human-agent teaming rarely explores the effect of artificial agent behavior on team performance. For example, timing of artificial agents in human-agent teams has received little attention as an important design parameter, despite timing often being considered a significant design parameter in traditional user interface design (Miller et al., 2001). In traditional human interface design, timing is typically a concern when the system exhibits unacceptable delays due to slow system response to human input, requiring design changes to reduce the perceived delay. In human-agent teams, the artificial agents do not necessarily respond to human input and can respond more rapidly to environmental or mission-based stimuli than a human teammate. This fast response permits an agent to improve system performance when system performance is limited by human response time.

Human information processing is often modeled as a four-stage process, including sensory processing, perception, decision making and response selection (Parasuraman, Sheridan, & Wickens, 2000). These stages are typically assumed to be performed as a serial sequence, with each of the four stages requiring a finite time period to complete. The time required to perform each stage is dependent upon the complexity of the task (Fitts & Peterson, 1964; Hyman, 1953) as well as human motivation and skill level (Dixon & Wickens, 2003). In multi-task environments, other concerns, such as task switching may introduce additional delays. An autonomous agent may perform a series of processes analogous to the four-stage human information process. Depending upon the system design, the autonomous agent may perform any of these four stages significantly faster or slower than a typical human operator, with the potential to perform these processes so rapidly as to appear instantaneous to the human operator. Therefore, a rapid response on the part of the autonomous agent may reduce the human's opportunity to respond to environmental stimuli.

Rouse constructed a queuing model to understand the effect of the relative speed of an autonomous agent on human involvement in a human-agent team (Rouse, 1977). This research illustrated that the proportion of decisions made by the autonomous agent within the team should increase as the autonomous system's speed increases with respect to the time required for the human to make a similar decision. The model indicated that the proportion of decisions performed by the autonomous agent was particularly high when the event rate was low. This research implies that during times of relatively low activity, a rapidly responding agent will perform the majority of actions, relegating the human to the role of a supervisor. Thus, the human will be forced to perform a vigilance task. As it is known that humans perform poorly in this role (Warm, Parasuraman, & Matthews, 2008), it would be expected that the performance of the team may well suffer when active human tasks are converted to passive activity due to the agent's rapid response.

The effect of varying the cycle time of adaptive automation has also been discussed in the autonomy literature (Hilburn, Molloy, Wong, & Parasuraman, 1993). This research indicated that time triggers have limited applicability. However, in this example, the automated system relied solely upon triggers that altered system state between fully manual and fully automatic for predetermined lengths of time; thus, requiring the human to perform all or none of the functions within any epoch (Feigh, Dorneich, & Hayes, 2012; Hilburn et al., 1993). More recently, automated systems have implemented safety features which activate when time is not available to permit a satisfactory human response to an impending vehicle collision (Bice, Skoog, & Howard, 1990; Rump, Steiner, & Douglas, 1996). These systems illustrate the utility of rapid automated response when the human is unable to respond in a timely fashion.

Despite early modeling research indicating the impact of agent timing on decision making and performance in human-agent teams, the impact of autonomous agent timing has not been investigated through human-in-the-loop research. As autonomous agents continue to be incorporated into dynamic and evolving environments, the effect of agent timing deserves further investigation. The moment the agent executes an action determines its timing when responding to an environmental or system generated event. For both humans and agents, the timing of an action is constrained by, but not determined by, the time required for decision-making. That is an action cannot be undertaken before a decision is made but the action can be deliberately delayed.

The current research sought to investigate the effect of agent delay time on human workload, as well as, team behavior and performance within a shared environment. To contribute towards the team objective, we recognize that the agent must consider multiple objectives and these objectives may influence the agent's desired timing. Specifically, the agent must complete tasks consistent with the