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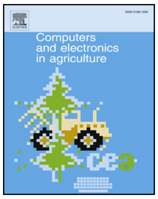

Original papers

Evaluating operator harvest technology within a high-fidelity combine simulator

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ABSTRACT

Farming today is more complex than it has ever been. Operators are increasingly reliant on technology to aid and improve harvest performance. New harvest technology is under development that will advise harvest operators on the proper adjustment of machine harvest settings, as well as automatically adjust these machine settings without operator intervention, improving the harvest performance of the machine, and reducing the cognitive load of the operator. In this work a high-fidelity, interactive harvest combine simulator is used to understand how harvest operators currently use existing harvest technology, and to evaluate the performance improvements provided by new prototype machine control algorithms and human control interface designs. The interactive harvest simulator is used to assess an intermediate advising step for machine controls adjustment compared with a path using fully autonomous machine adjustment. Testing novel harvest technologies using the virtual environment of the combine simulator introduces a specific set of constraints and challenges that are not found in most other vehicle simulation applications, including the need for accurate physical and visual crop flow representations and a requirement for realistic machine responses to a wide variety of operator input commands. Using a high-fidelity combine simulator for testing allows unique harvest scenarios to be repeated by experienced operators in a controlled virtual environment.

This study evaluates operator acceptance, performance, and feedback for two novel pieces of harvest technology, *Advisor* and *Director*. Advisor is an operator-in-the-loop system providing feedback on proper machine control adjustments during normal harvest operations. Director is designed to continuously monitor the overall harvest health and autonomously adjust the combine harvest settings. In this study, operators harvested the same virtual field twice, first using Advisor, and a second time using Director. Operators overwhelmingly perceived both the Advisor and Director systems as optimizing the harvest performance of the combine and recommended both Advisor and Director. The results presented in this work show that both systems improved the perceived harvest performance, although the Advisor was not as highly rated. Participants recommended the automated nature of Director, and both operator feedback and physiological measures indicates that this harvest technology reduced the cognitive load of the operator. This work demonstrates two main points. First, the interactive combine simulator can be used for evaluating novel harvest technology in the lab. Second, that operators can quickly acclimate to automation within the combine and were able to harvest in a more productive manner when using higher levels of automation.

1. Introduction

Harvest operators today face an increasing number of distractions and demands on their mental resources. Combine operators not only manage the physical crop harvesting process, they also must plan logistics for grain transport, analyze weather reports, communicate with outside operators, and take phone calls from a variety of sources. A potential solution for reducing the workload of the operator is to automate those aspects of tasks which demand high cognitive resources, such as the ongoing vigilance of driving and the complex input tasks required for machine adjustments. This approach has been shown to be effective in other comparable scenarios (Endsley and Kaber, 1999;

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Metzger and Parasuraman, 2001; Parasuraman et al., 2009). The tasks which demand the most of operators should be evaluated for potential automation benefits, such as the control and adjustments of the combine processing systems, including the fans, sieves, and implement arrangements. Automating the most important harvest controls can help reduce the overall cognitive load experienced by operators, as well as improve the performance from less experienced operators who might otherwise see low performance results. In this work, a new technology application is evaluated using two steps on the path to harvest automation, the first providing guidance for manual machine adjustments during harvesting and then the second fully automating the sensing and harvest adjustments required to improve the performance.

Two related technologies were evaluated in this study, *Advisor* and *Director*. Both technologies were developed by the research team and did not represent finished quality found in final production software interactions or robustness. Advisor technology offers expert level guidance to operators in real time via combine adjustment feedback and suggested actions. Performance gains have been demonstrated in other studies, where the assisted operator shows higher performance than fully manual or fully automated solutions in similar scenarios, (Endsley and Kaber, 1999; Endsley and Kiris, 1995). In this implementation, Advisor requires operators to input their observed harvest issues, accounts for the current system state of the combine overall, and delivers a recommended list of corrective changes in prioritized order. Because the Advisor must rely on the operator to identify and report issues, an implicit assumption is that the operators have enough basic knowledge of harvesting to initiate the system and report observed issues. After recommendations are made, the operator can either accept the current recommendation, view the next recommendation, or cancel the entire process. This affords the operator the opportunity to allow the adjustment to be made as suggested by Advisor, select an alternative action, or to cancel the process and make a manual change which may have been influenced by the earlier suggestions. The final step of the Advisor process then queries the operator to note whether the issue has been resolved or if a new issue is present. This answer can either end the engagement or begin anew with the new or modified issue.

Director is the next level of automation, where the system actively monitors the overall combine system state in real time and acts to improve harvest quality. After an initial setup to identify the harvesting preferences of the operator (e.g. Do you want a faster harvest with a lower quality sample or a slower harvest with a higher quality sample?) the system will make changes without interrupting the operator to improve the harvest process overall. Due to the ability of the Director to initiate change without involvement of the operator, operators with lower harvest knowledge stand to gain more benefit from this system as it has the capability to observe and autonomously make changes on issues that may have otherwise gone unnoticed. The system does notify the operator when a change is underway, but it does not have to wait for approval with every adjustment.

Both Advisor and Director represent incremental steps in available technology toward a fully automated harvesting system. These automation steps were designed to provide operator assistance without sacrificing quality. When comparing Advisor and Director to the established SAE Automated Driving Levels (SAE, 2014), Advisor falls within level 2 of *partial automation*, which requires multiple systems to be automated but ultimately requires the operator to still perform the remaining tasks to successfully operator the machine. Director then takes the next step and falls closer to level 3 of *conditional automation* where the operator hands over control of all aspects of the dynamic driving but needs to be present for intervention. With these automated driving levels to consider, the value of a guidance-based system, Advisor, can be adequately compared with the more automated system, Director. To understand the full value each of these systems provides, the current state of combine adjustment must be understood.

When a problem occurs during normal harvesting operations, current practice calls for the operator to use acquired knowledge to adjust the combine settings. When the operator does not know the correct solution, the process ends in one of three situations. The operator may (1) seek additional help, (2) ignore the potential issue, or (3) miss the harvest cue altogether. Seeking help requires time and will likely slow progress within the field because of the efforts required to contact an outside expert (e.g., “I have to call Dad.”), consult outside knowledge such as the harvest slide rule (Deere, 2013), review the troubleshooting guide (IH, 2009), or refer to the owner’s manual. If the operator simply ignores issues or misses harvest cues outright, the harvest process will result in lost grain loss and the operator is indirectly indicating low harvest knowledge. Both Advisor and Director can improve these known issues by providing a faster resource for outside information in Advisor and performing changes that would otherwise go untended with Director.

Several factors make it particularly difficult to test this highly specialized technology. First, it requires several factors—the right season, uniform crops in the field, an expensive harvest combine machine, and a human operator. The North American harvest season occurs only once per year, and most operators will not encounter these specific requirements outside of that window, so the technology is only sporadically needed. Testing the algorithms requires multiple runs through the field with a variety of crop conditions. Even the most uniform field and crops have unknown variations, and once a field is harvested, there is not a duplicate with which to compare results. Even obtaining the operator may be problematic, as any time spent away from harvest may have a high cost in terms of lost harvest opportunities. That said, real conditions will vary from the simulator conditions, sometimes drastically. The simulator will be unable to train for all potential field conditions but will still benefit the operator in a variety of ways, importantly with experiencing new technology.

The limited time window of operation and infrequent use of this type of technology makes designing for this specific audience difficult and testing it prior to implementation nearly impossible. However, implementing the prototype harvest technology within the high-fidelity combine simulator gives the operator the opportunity to acclimate to the new automation system, provides a baseline for performance, and offers feedback for technology they have yet to encounter in the field, all without the pressure of monetary loss when using their own crops and equipment. Specific harvest scenarios can be built within the virtual environment; therefore, operators can make all normal adjustments that would occur in a real combine as both the operator and the technology are evaluated. Moreover, a simple reset of the simulation presents each operator with an identical field and set of crop conditions during the test.

Harvest scenarios include relevant exterior graphical cues (e.g. crop height and color), interior instrument cues (e.g. loss monitor, moisture monitor), and expected auditory cues. An emphasis is placed on observing operator feedback including verbal, performance, and physiological. All operators indicated preference to a system which helps them identify potential issues and the less experienced operators strongly prefer the system which helps them perform at a level closer to an expert. The software, hardware, and external components utilized to perform this study are outlined in the methods section.

2. Background

Previous studies have shown that virtual environments and simulators are effective at training new technologies and developing new products, especially within domains which have highly specific or constrained use cases. Simulators and virtual environment training transfer work has found success in areas such as repairing the Hubble space telescope (Loftin and Kenney, 1995), fire-fighting aboard a naval ship (Tate et al., 1997), or even performing highly specialized medical procedures (Calatayud et al., 2010; Kruglikova et al., 2010; Triantafyllou et al., 2014).