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GREENSPACE: Virtual Reality Interface for Combine Operator Training

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Keywords
Automation systems, Control inputs, Control modes, Engineering design, Machine controls, Operator training, Precision farming, Virtual reality interfaces, hardware

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Comments
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The complexity of operating a farm combine has increased dramatically in recent years with the introduction of features including automatic guidance, precision farming, and sophisticated implements with specialized controls. In this work, we describe the development of a virtual reality interface for use in operating a combine while harvesting virtual crops. Using the actual combine cab hardware for control input commands and operational displays, we provide a virtual farm that allows the operator to operate every aspect of the combine while using the true set of buttons, levers, and switches for a realistic driving experience. This simulator is designed primarily for operator training on the adjustment and operation of the machine controls, the use of automatic guidance systems, and interaction with the precision farming automation systems. However, the simulator is also applicable for engineering design development, where new control modes and hardware could be assessed in a virtual environment.

1 Introduction

The use of a simulation interface for operator training has been commonplace in the aircraft industry for many years. Providing accurate operator control buttons and levers is important (Shiguang, Xu, Xiumin, & Qichang, 2011), and it is interesting to note that the use of a motion base for accurate pilot immersion has been rendered obsolete in the newest form of pilot training, aircraft drones. The importance of including hardware-in-the-loop during the design and development of automatic systems has been demonstrated, and realistic operator interfaces have been used to both design the control laws and verify the way that humans interact with the automation (Zhang, Reid, & Wu, 2000). Typically, these implementations use a custom-developed computer and data acquisition system as the interface between the operator input hardware and the test system hardware (Yoon, Cho, Kang, Koo, & Yi, 2010).

As the use of virtual reality (VR) has become widespread, new applications have been used for training humans in the operation of complex tasks, including maintenance (McLin & Chung, 1996), forestry machine training (Freund, Adam, Hoffmann, Rossmann, & Kraemer, 2000), and driving tasks (Cremer, Kearney, & Papelis, 1996). The operation of a harvesting combine is one complex task that does, indeed, require training! In this work, we have developed a VR interface for the purpose of presenting a realistic functional interface to a novice combine operator that accurately responds to human commands and reacts in the same manner as a true combine.

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Combines are used worldwide for a variety of crop harvesting, and have dramatically increased farm productivity. Over the years, the design and operation of these large machines has been enhanced through the use of computer technology, accurate electronic sensors, and fly-by-wire control. As an example, John Deere combines use a hydrostatic transmission to apply drive power to the wheels. Twenty-five years ago, the control handle the driver used to make the machine move was physically attached to the swash-plate of the hydrostat by means of a push-rod or cable. The operator used muscle power to tilt the swash-plate, and the flow of hydraulic fluid moved the machine forward. As computer technology improved, it became cost-effective to put a position sensor on the control handle, an actuator on the swash-plate, and a microprocessor in between to sense the command and implement the control action.

There are many potential advantages to using this type of computer control scheme, such as reduced weight and complexity from removing mechanical parts, the design flexibility of not needing physical proximity between the lever and the transmission, and performance improvements that may come from more accurate computer control. The big advantages come with the capability for using the computer to add functionality, such as all-wheel traction control.

Computer control has come to include the engine, harvest drive train, and steering; thus, it was a natural extension to introduce global position sensing (GPS) technology, and to automatically drive the machine. This allowed for more accurate seed planting, application of pesticides, and more efficient harvesting, eliminating missed spots or excessive overlap. Precision farming methods have been developed that can integrate the position of the vehicle, instantaneous crop yield rates, and soil composition maps so that the farmer can assess exactly the needs of the soil and the effects of fertilizer and herbicides on the crop output of any selected square meter of the field.

With the advent of autonomous vehicle control and the application of precision farming techniques for monitoring and controlling harvest operations, combines have become so complex that learning effective operation and control techniques has become a serious problem. For example, in order to implement effective control of the combine head, John Deere allows for no less than four different modes of control. The operator controls for this are part of the cornerpost display unit (CDU), and the operator interface buttons are shown in Figure 1.

Figure 1. *There are four automatic control modes for the combine header.*

What is the function each of these buttons? What are the four control modes, how do they work, and when should they be used? There are answers to these questions, of course: the design engineers developed the controls because customers requested solutions to problems that they encountered when harvesting crops. And the answers can be found in the comprehensive documentation meticulously compiled by the manufacturer. Thirty-three pages of the *Operator's Manual* describe in detail how to engage each mode and how each one works. Can you imagine if you had to read 33 pages of the automobile manual to find out how to use the cruise control of your rental car in Madrid, Spain? Yes, there are people who will do it, but not many.

Our objective in this work is to develop an accurate operator control interface to allow training on the function and use of the many combine functions available in a modern combine. While focused on a particular type of vehicle, we have generalized our approach to allow application to other vehicles that use a CAN-based distributed control structure, which includes most farm and construction vehicles.

2 Controller Area Network (CAN) Virtual Reality Interface

An important evolution in the mobility industry is the widespread use of controller area networks (CAN) for control and communication between the subsystems of a vehicle (Voss, 2005). Used on automobiles, farm vehicles, and construction equipment, CAN networks are a serial bus-based communications protocol used to connect the various computers, sensors, and controllers found in modern vehicles.

The CAN protocol is specified in detail by the ISO 11898 standard (International Standards Organization, 2003), and is explicitly defined for automotive applications by the SAE J1938 standard (SAE International, 2010). CAN systems offer the advantages of standardized hardware and software, high data and communications transfer rates, distributed control options, and low cost.

In the old days, an electric window on a car was controlled by a motor and switch. The driver would push the switch, energize the motor, and roll up the window. Problems with complexity ensued as designers offered the capability for the driver to operate the other three windows, requiring extra wires, switches, and two-way switch circuits.

Using a two-wire serial CAN bus approach, each switch is connected to a CAN node microprocessor that sends a message across the network when the switch is pressed: “Hello! This is the CAN node on the driver’s door, the ‘UP WINDOW’ button has been pressed.” On the other side of the vehicle, the rear passenger window motor, also connected to the bus through a CAN microprocessor, receives that message, which may have been sent specifically to that address or may have been broadcast to the entire network, and rolls up the window.

The advantages to using the CAN architecture in this example include reduced wiring, design flexibility in the placement of the switches and motors, and the capability to effect changes in other systems on the vehicle: for instance, the designers may want to turn off the air conditioner when the window is open. In that case, the same message would be received by the A/C controller and action would be taken.

Currently, work is being done to use the CAN interface to allow operator-in-the-loop simulations for tractor and construction equipment (Karkee, Steward, Kelkar, & Kemp, 2011), where the operator input controls and buttons use a CAN interface chip to sense control inputs (Pazul, 2009). This work is aimed at providing an interface to engineering analysis tools rather than a high-fidelity reproduction of the actual vehicle control and operation. In our system, we use a commercially available CAN to USB computer interface (Lawicel, 2007) to reproduce each of the machine controllers that is necessary for operation of the production vehicle. We have developed a software and message database structure that supports the communications required to allow the operator to use the vehicle controls as an interface for driving the combine in the VR simulation.

3 Virtual Reality Interface and GREENSPACE

Our GREENSPACE VR simulation allows the human operator to sit in a real combine seat with the actual operator controls and displays, while driving a simulated combine through a virtual farm field filled with simulated crops. Our software is based on the VR Juggler shareware (VR Juggler, 2010). This software provides a standard immersive interface for the graphics and display of the simulation.

As shown in Figure 2, graphics are provided that immerse the operator in the scene, and as the vehicle drives, all the appropriate bells and whistles appear on the in-cab displays, and the graphics representations of the machine, implement, and field behave correctly.

Figure 2. *Actual operator inputs drive the combine through the virtual farm field.*

In our approach to providing a VR interface for combine operation, we use the actual hardware that the operator would find in the cab to control the vehicle. This includes the steering wheel, the armrest control console with many buttons and switches, and the hydrostatic control handle, the corner post cab displays and buttons, and the precision farming touch-screen monitor. In the case of a John Deere Series 70 STS combine, there are several CAN controllers within the cab that monitor the states of these switches and send and receive messages based on the states and changes made by the operator.

However, there are many other CAN control nodes on a combine that we do not use for the VR interface. These include the engine controller, the transmission controller, the implement controller, harvest monitoring sensors and controllers, steering controller, and the GPS CAN nodes. While each of these controllers is vital for the operation of a real combine, the human operator does not interact with these directly, and we do not need them for our simulation. However, we do need many of the messages that are sent by these controllers. For instance, the engine controller monitors the oil pressure, and sends a status message at regular intervals. If the oil pressure on a combine gets low, serious damage can occur, costing thousands of dollars. If the cab CAN controller sees a “low oil” message, or goes too long without getting an “oil OK” message, that controller shuts off the machine, preventing catastrophic damage.

Our operator simulation interface uses “virtual controllers” to replace each of the missing hardware controllers. We developed a software representation for each of the controllers that is not directly used by the operator. The virtual controllers include:

1. Engine controller
2. Transmission controller
3. LC1 (harvest monitor and sensing)

4. LC2 (harvest monitor and sensing)
5. Implement controller
6. Steering control unit (SCU)
7. HMM (harvest monitor)
8. Starfire GPS

Each virtual controller is programmed to connect to the CAN bus using the correct address of the replaced hardware. The virtual controllers send and receive operationally critical messages, such as the engine oil pressure described previously. The virtual controllers do not necessarily replace every message sent and received by the true controller; for instance, the LC1 monitors many sensors, but all we need from it is a representation of how much virtual grain is being harvested. Many other messages are not needed, which may include messages between two virtual controllers that do not affect the machine motion or operator displays. All messages that do affect the operation of the machine are replicated in the virtual controllers and sent over the CAN bus.

The simulation of the virtual environment includes vehicle dynamics and kinematics. As the operator changes the steering input, a potentiometer measures the change, and a virtual steering control unit (SCU) turns the virtual wheel angle so that the virtual combine turns in the virtual field.

We have also included an engine dynamics model in the simulation, so that as the operator drives into the crop and begins to harvest, the additional load pulls the engine speed down slightly, and the virtual engine controller sends these changes to the cab displays for the operator. The true engine controller includes proprietary algorithms that are designed to optimize the engine performance and keep the engine RPMs steady while harvesting. We do not attempt to replicate this, but provide a simple first-order engine response that mimics the actual operation.

The simulation uses a graphical representation of the combine and harvesting implements. These are taken from the actual CAD design database, although they are modified to reduce the complexity and polygon count. The implement head is reconfigurable so that heads can be changed to harvest wheat, corn, and soybeans. While this operation must be done with tools in real life, our simulation allows for implement changes with the tap of the keyboard.

The farm scene used in the simulation includes the field, crop graphics, and surrounding scenes of houses, mountains, and other objects on the horizon to help provide motion cues as the operator drives and turns—in a large field of crop alone it can be difficult to get the sense of turning and these horizon objects help with the turn at the end of the row.

The crop models include a density map of the field that can be programmed in advance. Density changes in the crop are a naturally occurring feature and the density map provides for this feature in the simulation. A second field map assigns moisture content to each area of the field. Both maps are overlaid on the virtual farm field to provide realistic crop information. As on a true combine, the proprietary precision farming CAN computer node keeps track of the grain yield and moisture levels during harvest and uses this information to build harvest maps for the operator.

4 Operation of the User Interface and VR Simulation

The human operator can use the training simulator to harvest crops in exactly the same way that a real combine would be used. Climbing on the seat activates the weight sensor—a safety feature that prevents operation of the machine if there is no operator. This is important when the machine can drive itself in an autonomous mode! Turning on the key activates CAN messages in the hardware CAN CAB controller, which broadcasts the appropriate message. Various hardware and virtual CAN controllers receive the “key on” message and the cab comes on just as in a true combine—the engine starts and the multiple cab displays show the operator many vehicle status numbers such as engine RPM and temperature.

Next, the operator may choose to engage the header and turn on the reel. The yellow buttons on the armrest controller, shown in Figure 3, perform this function on the actual combine and on the simulator. The reel starts to turn in the graphical display, and the reel speed can be

Figure 3. *The operator drives the simulation with the same controls as the combine. The pair of switches (yellow on the controller) engage the header and reel.*

Figure 4. *The John Deere GS2 CAN controller performs precision farming data integration.*

adjusted using the correct controls and procedures from the physical armrest.

Also shown in Figure 3 is the multifunction control handle, which controls the hydrostatic transmission and has multifunction buttons that control the head position and orientation, unloading auger, and automatic head control functions. The operator can drive the combine by moving the handle, and can adjust the position and orientation of the head with the buttons. Within the simulation, all of these operator controls behave in exactly the same fashion as on the true combine.

Other buttons on the hydro handle activate the autonomous driving feature (AutoTrack) and the automatic precision farming mode (HarvestSmart). Because of the safety issues involved in having this giant machine drive itself, there are a host of checks, adjustments, and calibrations that the operator must perform to use these features. Just as in the true combine, the operator can perform these activities using the touch screen on the precision farming computer (GS2), as shown in Figure 4.

As the vehicle drives through the simulation, we keep track of the location, and convert this location to GPS coordinates, package the coordinates correctly for the CAN communications, and send them over the CAN bus to the precision farming computer. This computer is also a node on the CAN bus, and has been developed and built by John Deere IVS, a division of Deere, Inc. This CAN controller is top secret and contains proprietary precision farming monitoring and analysis software developed after many years of research and testing. We do not attempt to replicate this as a virtual controller; rather, we use our simulation to provide all the necessary signals from the harvest, such as harvest rate, grain loss, and moisture content. We then allow the black box to perform as designed: monitoring the harvest, building and displaying yield and moisture maps, and keeping track of harvested areas of the field.

Finally, the operator is free to harvest the field. As with a real combine, an operator can choose to drive the combine, but there are new features that allow the combine to optimize the speed and operation of the machine in an autonomous mode. Again, the operator can set up the simulated machine in exactly the same manner as the real one, adjusting such things as rotor speed and pressure, and engaging the automatic precision farming feature (HarvestSmart).

The virtual vehicle drives through the virtual field and the virtual CAN controllers (LC1 and LC2) keep track of the crop harvest rate, moisture content, and vehicle position. These values come from the virtual farm and the field maps, according to the assignment made before running the simulation. This and other information is packaged according to the CAN protocols, ISO 11898 and J1939, and then sent along the CAN bus where it is used for the precision farming functions.

5 Combine Training Seat Development

It is clear that the kinds of complex features found on a modern combine require significant training for the operator to learn how they are used. Currently, all of these features are described in detail in the *Operator's Manual*, but this manual is very thick and requires significant study for successful training. In addition, many of the step-by-step instructions in the manual are best done while at the machine, making it difficult to learn to use the most advanced features.

One method of training is to use an actual combine and have the training expert sit next to the operator to show how to use the advanced features. Clearly, this is an expensive and time-consuming solution. Further, if an operator needs instructions on how to harvest corn in the U.S., the only time that this can be done is during the fall harvest season, a very narrow time window which also corresponds to the busiest season for those who would be able to provide the training.

Using the VR Combine simulation tool described here, we have also developed a standalone combine buck. This is a seat and interface hardware that is designed to be used in either large-scale or personal training, without the need for using an actual combine as the training platform.

Shown in Figure 5, the buck is a mobile platform that includes the seat, steering wheel, armrest controls, cornerpost display, and the VR interface. This training buck can be used for one-on-one training as the expert stands next to the trainee, and allows for step-by-step instruction. The training seat is also applicable for large group training, where 10 or 20 seats can be placed in a large room and the expert conducts a training session where the trainees can follow along and actually practice the sequence of steps. Clearly, this is a significant improvement over the current methods available.

Because an actual combine travels at relatively low speeds, and except in rare cases operates on fairly level terrain, we have not included a full motion base as part of the simulator. The objective of using the simulator for instruction and training does not require the additional complexity of actual vehicle motion. We have, however, included vehicle sounds as part of the simulation. During operation, engine growl alerts the operator when the key is turned on and when crop harvesting and unloading loads drag down the engine. A decent set of audio speakers with a sub-woofer provide adequate audio and vibratory cues to the operator.

The VR interface and training buck also hold potential for research. Because the human element is so important in the development of autonomous features, new algorithms can be tested and verified using the VR system. Operator perceptions can be observed and analyzed in a controlled environment. The VR training buck could be used for operator skills assessment, and can be used to develop and evaluate the effectiveness of various training curricula.

Finally, this system is useful for developing autonomous control algorithms. Because the combine drives through a virtual field, the crop properties are set in the program. Various combinations of these crop properties can be programmed to test the performance of new algorithms. This simulation is the only place in the world where two operators can harvest exactly the same field—in all other cases, real fields can only be harvested

Figure 5. *The GREENSPACE stand-alone combine simulator buck at Iowa State University.*

once—allowing the comparison of operator skills and the effectiveness of new algorithms.

Test results for the GREENSPACE training system up to this point are heuristic. We have had John Deere engineers review the operation and fidelity of the system using an extensive checklist to verify that each possible operator command has the same result in the simulator as on the actual vehicle. During a presentation at the Harvester Works International Headquarters in Moline, Illinois, a young farm boy from Oklahoma was there for an interview, and he sat down and started driving the simulator. He set up the field perimeter, adjusted the header control, separator, and fan speeds, and concave and drum settings. Next, he initialized the AutoTrack feature and proceeded to harvest the entire field. With a background in both agriculture and computer games, he was thrilled.

During another presentation, a person with no combine experience was trained to set up and harvest as described in the previous paragraph, and then attention was turned to a dealer who was interested in learning more about the opportunities for developing a commercial version for training. As we returned our attention to the current simulator, the neophyte had moved out of the seat and was training the next new recruit! It was quite a positive statement about the efficacy of the training seat.

Conclusion

In this work, we developed a VR interface for use in training combine operators on the many details necessary for effective use of a modern combine. The current training approach is to use an actual combine with a teacher sitting next to the driver. This is clearly expensive, and training can only be done at harvest times—just when experienced operators are needed elsewhere.

We are currently pushing this development forward in two areas; the first is to explore the detailed requirements for providing a commercial version of the seat. This includes developing physical hardware support for broken parts, devising software support to correct for any overlooked features, as well as planning for version changes and software upgrades from the manufacturer.

In addition, we are looking at using this simulation for both engineering evaluations and operator testing. The accuracy of the operator input and vehicle response allows for the addition and evaluation of new or planned features, and once these features are implemented, we are planning relevant tests to evaluate performance improvement due to the new automation.

Our stand-alone training seat provides a realistic interface that allows group training, provides repeatability for possible performance assessment, and can be used for training at any time, particularly in the winter months, when operators typically are not in high demand. The GREENSPACE Virtual Reality Interface for Combine Operator Training offers the potential for training cost savings and performance improvement.

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