DT Controls: Adding Identity to Physical Interfaces

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ABSTRACT
In this paper, we show how traditional physical interface components such as switches, levers, knobs and touch screens can be easily modified to identify who is activating each control. This allows us to change the function performed by the control, and the sensory feedback provided by the control itself, dependent upon the user. An auditing function is also available that logs each user's actions. We describe a number of example usage scenarios for our technique, and present two sample implementations.

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General terms: Design, Human Factors

Keywords: Identity, DiamondTouch, Multi-User, Haptics, Physical Interfaces, Auditing

INTRODUCTION
Control rooms, cockpits and dashboards are all examples of multi-user control systems. In each of these cases, there can be two or more users where each can manipulate the various controls. Current systems have no way of easily distinguishing which user has activated a particular control. In many cases, it does not matter who activated a control, but, in many other cases, knowing who activated a control can have important benefits. This is best illustrated through some simple examples.

Consider the case of an airline cockpit. Many of these are instrumented to record every action taken by the pilots. This data is typically used to help understand what happened in an accident, but can also be used for training and evaluation purposes. Currently, it is difficult to know whether the pilot or the co-pilot actuated a particular control. If this data were easily available, it could be used to identify training or design deficiencies, or perhaps indicate physical impairments of a particular pilot.

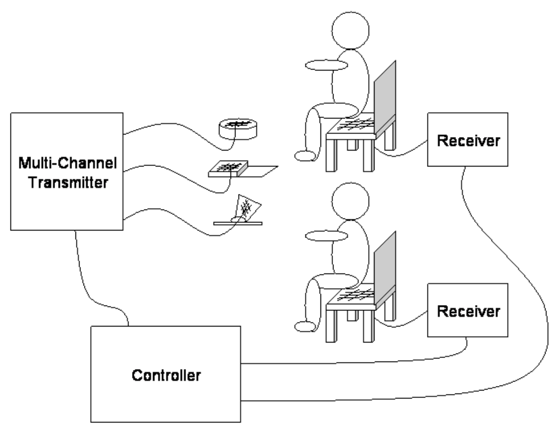

Figure 1: Block Diagram of a DT Controls System

A problem seen in modern vehicles is the excessive number and complexity of controls. For example, many cars have separate window, seat adjustment, and lock controls for each seat. If the vehicle also has audio and environmental controls for each seat, the number of controls becomes very large. Not only is this expensive, but it can be very confusing. Sometimes, the sheer number of controls means that they must be made very small to physically fit within a reasonable area, decreasing their usability. If the system could tell which seat the user was in, there could be a single set of controls, and those would only operate systems pertaining to that particular user. Thus, the number of controls could be dramatically reduced, wiring and hardware costs reduced, and operation greatly simplified.

In this paper, we propose a new technique to discriminate among users of physical controls. It works by placing a uniquely identifiable signal near the surface of each control to be monitored. Each user has a separate receiver on or near their person. When a user approaches a control, the signal is capacitively coupled through the user to that user's receiver. By examining the received signal, the system can determine which controls that user is currently near. This information can be recorded (to provide an auditing function), and/or it can be used to modify the functionality and/or behavior of each control.

BACKGROUND

Many current systems attempt to identify a user and change behavior accordingly. Logging into a computer network is a common example. However, it is presumed that only one user at a time will attempt to operate the physical interface at a particular workstation. The system has no way of knowing if a coworker has reached over to type or control the mouse.

The Personal Area Network (PAN) [1-2] is a system for transferring data by touch. It uses low frequency electric fields passed through the body of the user. Data transferred can include identity, so a properly enabled doorknob could be programmed to only respond to particular users. Unfortunately, this system was not designed for control panel applications and quickly becomes unwieldy as an identification method for a complex system. Adding PAN interfaces to a large number of controls would be prohibitively expensive. Also, there would be significant data collision problems to solve if multiple controls were operated simultaneously by a single user. A recent PAN system, RedTacton [3], appears to have addressed the collision issues, but at even higher unit implementation costs.

The Fingerprint User Interface [4] is a system for operating devices based on the fingerprint of the particular user. This allows functionality to vary not only between users, but between different fingers of the same user. While one could imagine adding fingerprint scanners to each control in a large panel, the cost would be prohibitive. Also, it is difficult to imagine how one would add a fingerprint scanner to a dial or a touch screen.

DiamondTouch [5] is an example of a true simultaneous, multi-user interface device and has many desirable properties. A DiamondTouch touch surface includes hundreds of antennas where each transmits a uniquely identifiable signal. By examining how these signals are coupled through a user, the system determines where the user is touching. Giving each user a separate receiver allows the system to uniquely identify the touches of each user. Unfortunately, DiamondTouch has been restricted to special touch surfaces with embedded antenna patterns; it is not practical for use with arbitrary physical controls.

In this work, we extend the DiamondTouch concept to generic physical control interfaces. As such, we refer to this work as “DiamondTouch Controls,” or simply “DT Controls.” We will show how typical controls such as switches, levers, knobs and even touch screens can be easily modified to provide identity information.

SYSTEM OVERVIEW

The basic building blocks of a DT Controls system are shown in Figure 1. A multi-channel transmitter creates a large number of uniquely identifiable signals. These signals are individually routed to insulated, conducting surfaces in the knobs, switches, etc. that comprise the operator interface. When a user operates a control, the corresponding signal is capacitively coupled through that user to a receiver. Each user has a separate receiver. Usually, we place the receive antennas inside the chairs of the users to achieve excellent capacitive coupling in an unobtrusive form. A master controller receives signal strength data from the receivers, and combines this with state data from the controls to perform the appropriate function. This is essentially a DiamondTouch system where the surface antennas have been separated out and placed inside the various controls. In fact, our demonstration systems are constructed from old DiamondTouch components described in [5].

Modifying a control for use in a DT Controls system is straightforward in most cases. For each control, the uniquely identifiable signal is connected to an insulated conducting surface that, by design, the users must be very near in order to operate the control. The goal is to have adequate capacitive coupling to the user only when the user is near the control.

One may wonder why the conducting surface must be insulated. In general, we want to be able to deal with the case of a single user simultaneously operating numerous controls. If the surfaces were uninsulated, touching one control would make it difficult to detect the capacitive coupling to other controls.

Figure 2: A push button which has been modified for DT Controls use. Note the copper foil on the inside top surface.

EXAMPLE DT CONTROLS

Push Button

Figure 2 shows the details of a push button switch which has been suitably modified. In this case, a small patch of copper tape has been added to the back surface of the switch. The plastic of the switch provides an insulator. In the case of a metal switch, the switch body itself could be used as the conductor, but a separate insulating layer would need to be added. Thick, rubberized paints, such as those used for coating tool handles, are ideal for this purpose.

Lockout Mechanism

An interesting feature of the DT Controls system is that the user can typically be sensed slightly before operating the control. This can be very useful. For example, if only certain users have permission to turn a dial, the dial can remain physically locked in position until just before a privileged user attempts to turn it, eliminating any perceived unlocking delay. Figure 3 shows a dial locking mechanism.

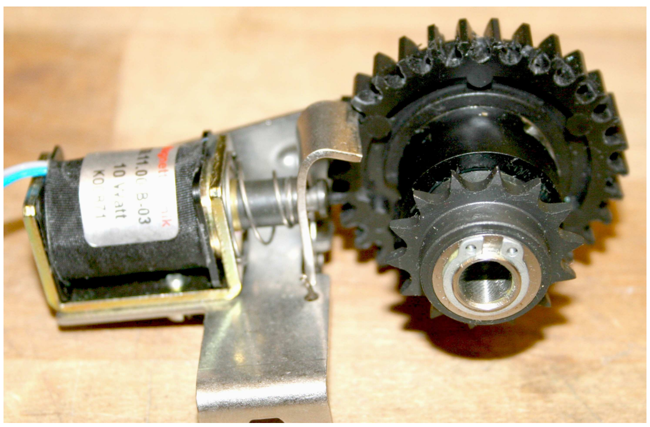

Figure 3: A dial locking mechanism. The mechanism is normally locked. Applying power to the solenoid releases the mechanism to rotate freely.

Touch Screen

LCD touch screen displays are an example of a common control for which it would be difficult to modify the surface without destroying the functionality of the device. Figure 4 illustrates the construction of a typical resistive touch screen [6]. There are two transparent resistive layers, separated by spacer dots. When a user touches the screen, the flexible top layer deforms and physically touches the bottom layer. Voltages are applied to one of the layers so that a voltage gradient is created across the sheet, while the other sheet is used as a conductor to measure the voltage on the first sheet at the point of contact. The measurement is then repeated with the voltage gradient in a mostly orthogonal direction. On a 4-wire screen, the two different voltage gradients are done on separate sheets, with the other sheet playing the role of the conductive contact. On a 5-wire screen, the gradients are always imposed on the bottom sheet.

In order to add an identity function to these standard resistive touch screens, we simply need to apply a uniquely identifiable signal to the top sheet in a way that does not interfere with the measurement function. The easiest way to do this is by reserving a small time slot between measurements during which the top sheet is modulated. Since our demo systems use time division multiplexing to create the unique signals, it is a simple matter to reserve a brief slot for the touch screen surface. (Time division multiplexing means that we modulate each surface in turn so we can know which signal we are receiving from the time we are receiving it. See [5] for details on other options.)

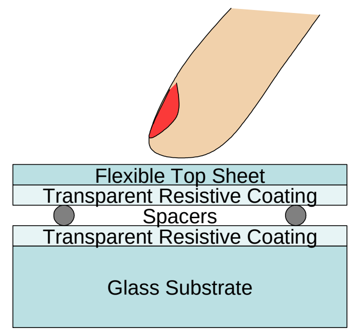

Figure 4: Cross section of a typical resistive touch screen. When finger pressure is applied, the top sheet deforms to make electrical contact between the two resistive layers.

USER-DEPENDENT CONTROL BEHAVIOR

In addition to changing the function of a control based upon who is using it, we can also modify the behavior of the control itself. We distinguish a widget's *function* and its *behavior*. *Function* refers to the action the control causes to happen (e.g., heat the driver's seat vs. heat the passenger's seat); *behavior* refers to the feel of the control itself as described below.

We note that some other systems have used identity information to modify *software* widgets' functions and behaviors in traditional GUI settings [7] [8] [9] [10]. Pebbles [7] uses PDAs to differentiate its users. It can then selectively gray out menu-options on a per-user basis, in essence locking out a user from using that widget. This is similar to our example of a dial which is physically unlocked only for authorized users. Extending this idea, it is possible to more generally change the look, feel and sound of a control based upon the person interacting with it.

In [11], it has been shown that a very simple force sensor and solenoid mechanism can provide a rich variety of haptic experiences. For example, the feel of single and multi-level buttons (e.g. digital camera shutter – focus, then shoot) can be programmatically created. If different users have different functionality from their controls, the controls can feel different to reflect this.

In addition to user-dependent haptic feedback, other sensory mechanisms can be engaged in a user-dependent way. If a car passenger is adjusting his or her seat, it might be helpful to have an audio alert to indicate when the limit of movement is reached. However, there is no need to disturb the driver with this irrelevant information. The audio can be directed in such a fashion as to only be heard by the passenger. Similarly, a shared push-to-talk button can direct a microphone array to the person requesting to give speech input.

TRUE IDENTITY

One drawback of the DT Controls system is that it only tells you which receiver was coupled to a particular control. In practical terms, this means that the system knows from which seat (presuming the usual seat-based receivers) the control was activated, but not necessarily the identity of that person.

In order to get true identity, an alternate identification means is necessary. Possibilities include a login procedure with a password, biometric sensors, RFID tags, etc. If the receivers are seat-based, it is easy to tell (via weight or capacitance) when a person leaves and a new person has entered the seat. All critical controls would be disabled until the new person is properly identified. A fingerprint scanner is a particularly robust identity mechanism because the scanner itself can be DT Controls-enabled to help verify that the finger in the scanner really does belong to the person currently in the chair.

In some cases, it is more important to know the class of user rather than the actual identity. For example, it may be important to lock out young children from operating certain devices. Various metrics can be used to ascertain this sort of class information. In the case of identifying a child, height, weight, voice pitch, etc. can all be used, singularly, or in combination, to help with classification. (Many vehicles already have occupant sensors that provide this type of information as part of the airbag control system.) In yet other cases, the role of the user is sufficient – pilot vs. co-pilot, driver vs. passenger. Roles can often be determined from position alone.

DEMONSTRATION SYSTEMS

In order to prove the DT Controls concept, we created hardware for two demo systems. The first has four simple push buttons. The second uses an LCD resistive touch screen.

Button Demo

The hardware for the button demo is shown in Figures 5 and 6. There are four push-button switches, modified for use as DT Controls devices, mounted in a two-by-two grid on a Plexiglas sheet. Although the system only has four buttons, the transmitter hardware could support several hundred unique signals while maintaining a 30Hz refresh rate. Similarly, there are only two receivers on the demo, but more could be added, well beyond the reasonable seating capacity in front of the controls.

The main controller is a standard DiamondTouch [5] controller that has been modified to also read the state of the buttons and report the information back via a serial link. Each receiver (a DiamondTouch receiver) also has its own serial data link. For convenience, we use a four port USB to serial adapter, resulting in a single USB connection for the apparatus.

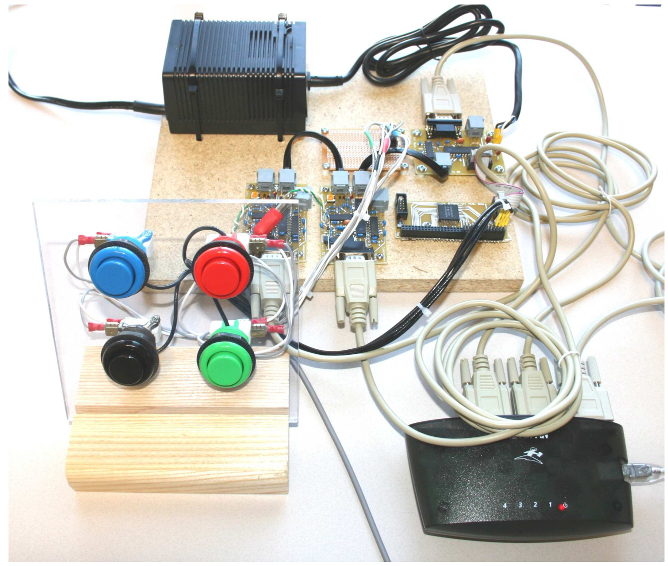

Figure 5: DT Controls push button demo has four buttons and receivers for two users.

Figure 6: DT Controls receiver pad. There is one for each user.

A simple test application is shown in figure 7. Here, the screen shows both the button state and the coupling from each user. A button press is indicated with a filled circle including the number of the user pressing the button. The outer annulus indicates user coupling, filling in the left or right halves to indicate each user.

In addition to the test system, we currently have two automotive applications and a multi-user game that work with the button demo hardware. These are intended to illustrate new interface techniques that are made possible by using DT Controls.

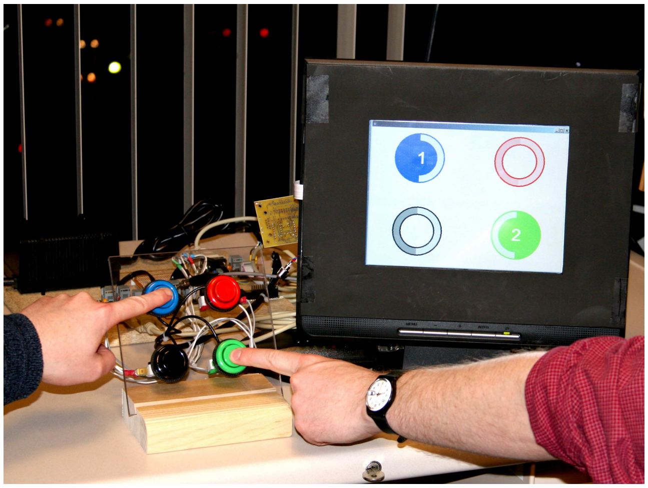

Figure 7: A simple DT Controls test application. The screen indicates which user is pressing each button.

Our first demonstration application, shown in Figure 8, is an example of mediating control permissions through user identification. This application models the use of up-down switches to control the windows of a car. The button panel is representative of the standard window controls in a car, but in this case they are shared between the driver and passenger, either on the dashboard or on the center console. Car windows are usually controlled by a two-way rocker switch. In our demo, each vertical pair of buttons models a single rocker switch, controlling a single window. We identify the roles of two users, driver and passenger, by the seats that they are sitting in. The two left buttons control the up and down motion of the driver's window and the two right buttons control the up and down motion of the passenger's window.

When the passenger presses the 'up' or 'down' button for their window, the system responds in the expected manner. If the passenger attempts to raise or lower the driver's window, the system ignores their input. The driver has the authority to operate not only his or her own window, but also the passenger's window.

Situations often arise in multi-user systems in which multiple people are issuing conflicting commands simultaneously, either intentionally or accidentally. If a situation arises in which the driver and passenger are issuing conflicting commands (such as when the passenger is pressing 'up' and the driver is pressing 'down' for the same window), the system ignores the input of the passenger and obeys the driver.

Our second automotive demonstration application is an example of multiplexing function through role identification. We again identify the two users by the seats that they are sitting in. In this example shown in Figure 9, we use horizontal pairs of DT Controls buttons to represent two-way rocker switches. Each pair represents a single seat control. The top pair of buttons tilts a seat forward and backward, and the bottom pair moves a seat base forward and backward. The same set of seat controls is shared between the two users. Because the receivers are placed within the car seats, the system is able to map input from each user to functions that control the appropriate seat. Both the driver and the passenger can adjust their seats simultaneously without interfering with one another's input, and can even act upon the same DT Controls button at the same time. It is worth noting that without DT Controls, this automobile would need twice as many controls for adjusting the driver and passenger seats, adding to the cost of the automobile and to the confusion of the dashboard interface.

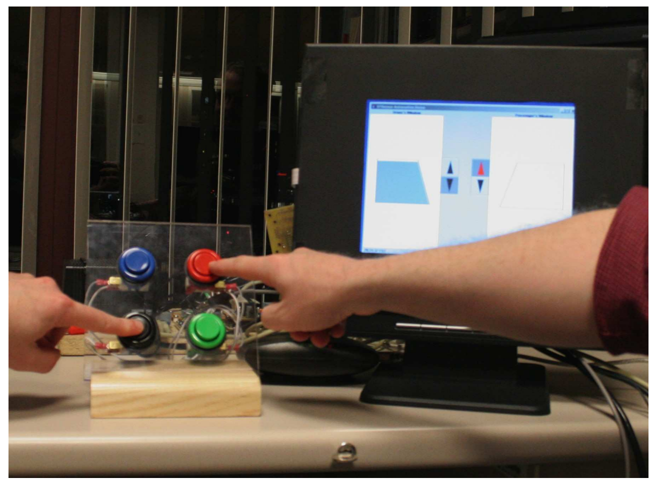

Figure 8: Shared automotive window controls demo.

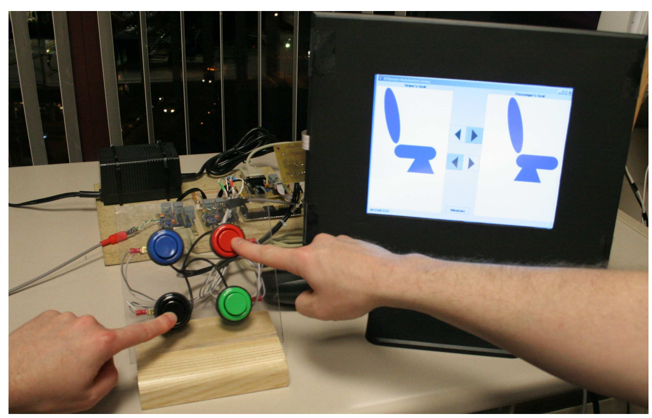

Figure 9: Shared automotive seat controls demo.

Finally, we built a collaborative multi-player variation of the popular children's game "Simon". In the game "Simon", each of four buttons is mapped to an individual sound. A single player must listen to and then repeat patterns of sounds by pressing these buttons in the correct sequence. In multi-player Simon, each player has a distinctive set of sounds, and these are intermixed in a random sequence. The two person team loses if they either press the wrong sequence of buttons or if a correct button is pressed by the wrong player. Success in multi-player Simon depends on turn taking and cooperation.

Figure 10: 5-wire, resistive touch screen.

Touch Screen Demo

The touch screen demo uses an Elo SCN-AT (E274) 5-wire, resistive touch screen shown in Figure 10. It has an active area of approximately 19.7cm x 14.8cm. Lacking an appropriately sized LCD panel, this was mounted on a standard 38cm diagonal LCD monitor, with a panel to mask off the unused screen area.

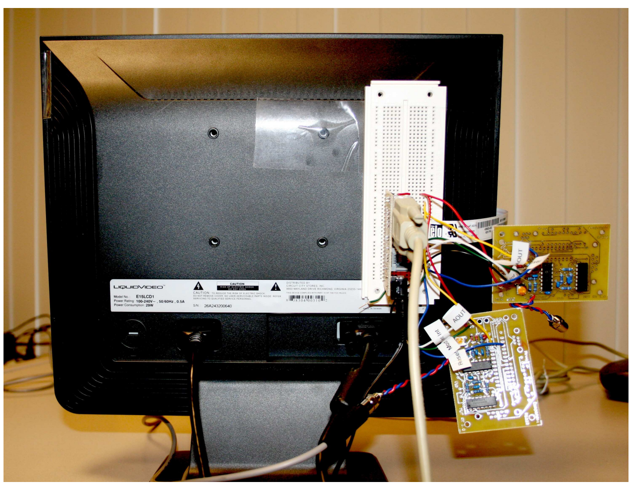

Figure 11: Rear view of LCD monitor with a custom 5-wire, resistive touch screen controller for DT Controls. The two receiver boards have been carefully arranged to achieve the much sought after “crude demo” appearance.

The touch screen is driven by a custom controller based on a PIC16F876. It performs all of the traditional touch screen controller functions, as well as providing surface modulation and receiver synchronization. There are two receivers. Once again, the receivers are DiamondTouch [5] receiver boards, but they have been modified to allow control from the single PIC16F876. All data is transmitted via a single serial interface.

The touch panel demo hardware, shown in Figure 11, can be used with the two automotive demo applications described above. In each case, there are a set of graphical widgets on the touch screen corresponding to the push buttons. The users touch the screen in order to actuate the buttons and the system mediates permissions and multiplexes functions based on the user role. These are shown in Figures 12 and 13.

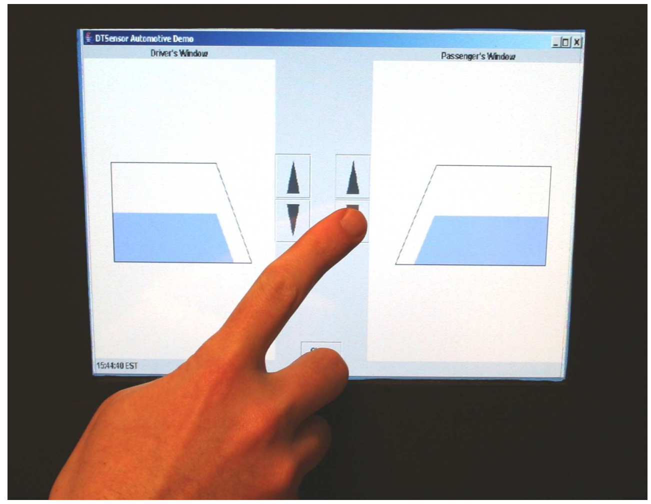

Figure 12: Shared automotive window control demo on a standard touch screen with a custom controller to provide DT Controls functionality.

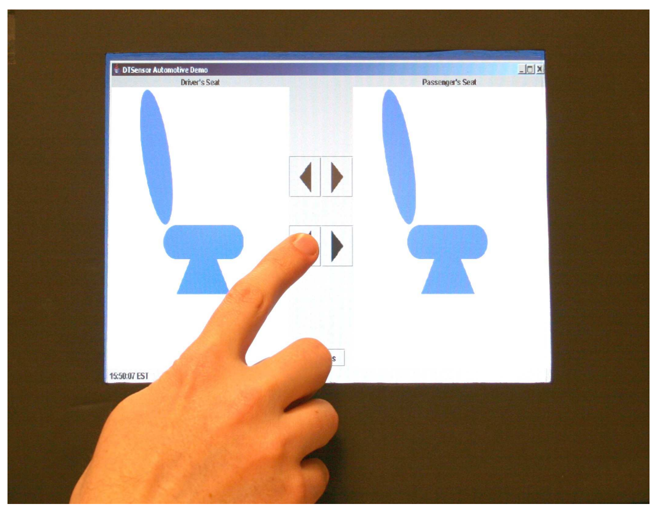

Figure 13: Shared automotive seat control demo on a standard touch screen with a custom controller to provide DT Controls functionality.

Unlike the button versions, the touch panel is somewhat more restricted in functionality – only one person at a time may operate the on-screen controls. Resistive touch screens are not designed to accept simultaneous touch events. When two or more points are touched, an alternative current path is created which distorts the presumed linear voltage gradient on the resistive sheet. In this circumstance, most touch screen controllers erroneously report a touch somewhere in between the actual touch locations. An advantage of having a DT Controls enabled touch screen is that it can detect when two users are attempting to operate the system simultaneously, and take appropriate action.

FUTURE APPLICATIONS

Automobile systems pose difficult safety issues. A driver can become distracted while trying to operate these systems, increasing the chances of an accident occurring. DT Controls can reduce the number of controls in a vehicle. This decreases the time wasted hunting for a specific control, and should decrease eyes-off-the-road time. Another way to reduce driver distraction is to present information to the occupants based on their role. For example, the system might provide spoken feedback to the driver, but present the same feedback to a passenger in visual form.

In order to prevent distraction while driving, some navigation systems disable input when the vehicle is in motion. While well intentioned, this approach has the frustrating drawback that the system also prevents use by a passenger for whom distraction is not an issue. Using DT Controls, a navigation system could differentiate among the different users, and could respond appropriately, allowing a passenger to enter data while the vehicle is moving, but locking out the driver.

Another promising application of DT Controls is in the field of workflow and task modeling and analysis. For single user applications, a log of a subject's input and interaction aids the efficiency expert in understanding the sequence of actions taken by an individual to perform the task at hand. Given a good understanding of the task, this expert can suggest improvements to tools and processes. However, for multi-user systems, an anonymous log of actions is insufficient. Analysts currently rely on video of the subjects at work in order to assign actions to individuals, often transcribing many hours of recordings by hand.

A DT Controls enabled testing lab would log not only what actions occurred when, but also who performed them. This type of audit trail could be extremely valuable to those who study the complex web of parallel actions performed by groups of people. Furthermore, by sensing proximity, a DT Controls enabled testing lab could determine if a subject temporarily reached toward a control before reconsidering an action.

This proximity control could also be an important part of post-accident analysis in cockpit and control room applications. In addition to a detailed record of who performed what action, proximity duration can give important clues as to what actions a user was considering and/or whether a user was anticipating some action by holding their hand over a control for an extended time.

Another cockpit application enabled by this technology is to require more than one user to be touching a control in order to enable an action. For example, it is a common convention that both the pilot and co-pilot of an airplane be actuating the throttle on takeoff. This convention could be enforced using DT Controls.

CONCLUSION

We have described and demonstrated a simple and inexpensive method to add identity information to common physical controls in a multi-user environment, and discussed various applications. The identity information allows us to change both the function and behavior of interfaces, while improving safety and usability for the end user. Our approach opens new avenues for exploring multi-user interfaces as well as improving traditional interfaces.

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REFERENCES

1. Zimmerman, T, “Personal area networks (PAN): Near-field intra-body communication.”, *IBM Systems Journal*, 35:, pp. 609--618, 1996.

2. Partridge, K; Dahlquist, B; Veiseh, A; Cain, A ; Foreman, A ; Goldberg, J; Borriello, G, “Empirical Measurements of Intrabody Communication performance under varied physical configurations”, *Proceedings of the 14th annual ACM symposium on User interface software and technology(UIST 2001)*, ISBN:1-58113-438-X, pp 183-190, 2001

3. RedTacton. http://www.redtacton.com/

4. Sugiura, A.; Koseki, Y., “A User Interface using Fingerprint Recognition: Holding Commands and Data Objects on Fingers”, *Proceedings of the 11th annual ACM symposium on User interface software and technology (UIST'98)*, ISBN: 0-58113-034-1, pp. 71-79, 1998

5. Dietz, P.H.; Leigh, D.L., "DiamondTouch: A Multi-User Touch Technology", *Proceedings of the 14th annual ACM Symposium on User Interface Software and Technology (UIST)*, ISBN: 1-58113-438-X, pps 219-226, November 2001

6. How an AccuTouch five-wire resistive touchscreen works - Elo TouchSystems: *http://www.elotouch.com/products/accutec/accworks.asp*

7. Myers, B.; Stiel, H.; Gargiulo, R., “Collaboration using multiple PDAs connected to a PC”, *Proceedings of the 1998 ACM conference on Computer Supported Cooperative Work (CSCW)*, ISBN:1-58113-009-0, pp. 285 – 294, 1998.

8. Bier, E. A.; Freeman, S., "MMM: a user interface architecture for shared editors on a single screen", *Proceedings of the 4th Annual ACM Symposium on User Interface Software and Technology (UIST)*, ISBN:0-89791-451-1, pp. 79 – 86, 1991.

9. Shen, C.; Vernier, F.D.; Forlines, C.; Ringel, M., "DiamondSpin: An Extensible Toolkit for Around-the-Table Interaction", *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, ISBN:1-58113-702-8, pp. 167 – 174, 2004.

10. Ryall, K.; Esenther, A.; Everitt, K.; Forlines, C.; Ringel Morris, M.; Shen, C.; Shipman, S.; Vernier, F., "iD-widgets: Parameterizing Widgets by User Identity," *Tenth IFIP TC13 International Conference on Human-Computer Interaction*, scheduled to appear.

11. Lee, J.C.; Dietz, P.H.; Leigh, D.; Yerazunis, W.S.; Hudson, S.E., "Haptic Pen: A Tactile Feedback Stylus for Touch Screens," *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology (UIST)*, ISBN: 1-58113-957-8, pp. 291-294, October 2004.