Scheduling home control devices: design issues and usability evaluation of four touchscreen interfaces

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This article describes four different user interfaces supporting scheduling two-state (ON/OFF) devices over time periods ranging from minutes to days. The touchscreen-based user interfaces including a digital 12-h clock, 24-h linear and 24-h dial prototypes are described and compared on a feature by feature basis. A formative usability test with 14 subjects, feedback from more than 30 reviewers, and the flexibility to add functions favour the 24-h linear version.

1. Introduction

Contemporary homes include a large number of electronically controlled devices such as microwave ovens, VCRs, heating/cooling systems and security systems which can be scheduled to start and stop functioning at given times (Smith, 1988; Elmer-DeWitt, 1989; Johnson, 1989). Typically each device has its own interface. As the number of devices in a home increases so does the mental load required to operate the devices, since different procedures must be employed to operate each device. Additionally, poorly designed user interfaces can make the scheduling task frustrating and difficult.

A solution to the problem of multiple user interfaces is to provide a home automation system consisting of a single user interface and the necessary hardware to control all the devices in the home using this interface. Such a user interface must then be general enough to support scheduling varied devices for a variety of tasks.

This research explores different mechanisms for scheduling two-state (ON/OFF) devices to allow novice or occasional users to schedule events easily and correctly.

The use and representation of time is a strong component of Western culture (Zerubavel, 1981; McCarthy, 1947). Our active life is cadenced by watches, personal calendars and alarm clocks. Since one of our goals is to design user interfaces taking advantage of the user's pre-existent knowledge (“in the head?”) (Norman, 1988), it is important for a scheduling interface to make the best use of the common representation of the time: clocks, calendars etc. Examples of the difficulties encountered by occasional users dealing with scheduling tasks are commonly reported, especially with VCRs which are well known to be frustrating (Nemy, 1989;
Norman, 1988). Nevertheless, only a few studies are attempting to understand or solve this problem (Sebillote, 1990; Robson, 1990; Hoffberg, 1991).

The scheduling of an event is also a data entry task in the sense that users have to enter values such as dates, times and number of hours. Data entry has been well studied (Kantowitz & Sorkin, 1983; Seibel, 1972), especially the entry of text from a keyboard, but also the use of dials and knobs which are more closely related to our watches. However, little can be found in the literature specifically related to the entry of temporal information. Weekly calendars have been used to ease the interpretation of the result of the scheduling of group meetings (Beard et al., 1990). Gould et al. (1989) compared entry and selection methods for specifying dates. The entry methods were found to be faster and more accurate than the selection methods but all methods used only the keyboard. Setting clocks with alarms is a standard feature of the Macintosh and Windows 3-0 desktop environment. More elaborate scheduling of actions is possible in the Hewlett-Packard NewWave Agent facility that also allows repeated events. In the Unix environment the scheduling of processes or messages is available but designed mainly for expert users. Krishnamurthy and Rosenblum (1991) offer a command language approach to specifying times and repeated events.

1.1. EXISTING HOME CONTROL SCHEDULING DEVICES

Simple scheduling devices can be found in stores and in our appliances (stoves, alarm clocks etc). They use either a dial (12 or 24 h) or a digital display. When a dial is used, one turn of the dial is the maximum period usable which is either 12 or 24 h according to the dial. Two separate dials are sometimes used to specify the start time and the duration or stop time. The precision is generally poor. Users either turn the whole dial, position hands or turn a knob which positions the hands. Another common technique is to use pins on the circumference of the dial, which can be pushed or pulled to mark the ON period.

When a digital display is used, the precision is good, the number of functions is increased since it can give the current time, allows multiple alarms etc. However, users are likely to need a manual to learn all the functions and retention may be poor. In some cases, the number of buttons is very limited to bring the cost or space down (e.g. on a alarm clock), therefore increasing the number of touches or the complexity of button combinations. For example, up to 59 touches may be required to change the minute value of an alarm with a single button.

The VCR is the appliance which stands to benefit the most from improved scheduling interfaces since one key feature is its scheduled recording capabilities (Nemy, 1989). Most VCR scheduling interfaces are digital and use a numeric keypad and/or specialized buttons. They use a small LCD display for the current time and also provide minimum feedback when a scheduling task is performed. The order of the data entry and the meaning of the numerous special buttons have to be learned. The editing of multiple events is difficult. Newer VCRs use the television screen during the interaction. The subtasks can be described: “Now type the channel number”, and selections can be made from menus. Finally, another technique for the VCR is the use of bar codes. This technique is at its best when the user has access to a printed TV guide which associates a bar code with each program.
description. (These guides are already used in Europe and Japan.) A simple scan of the bar code schedules a program to be recorded. Instead of specifying days, times and channels, users only specify the program they want to record. The cognitive load associated with the scheduling task is greatly reduced. Similarly some TV guides are now providing a code number for each program which can be keyed in the VCR. Unfortunately these last two techniques do not generalize well to other devices found in the house: only a generic calendar can be used and dates and times still have to be specified.

In the industrial or management world, the word “scheduling” carries a far more complex meaning and is mainly associated with scheduling techniques (like CPM, PERT etc.). Computers are heavily used to apply those techniques and automatically plan the scheduling of construction, transportation, school classes and use of rooms, etc. Here dates and times are calculated. Only in the editing phase are there user interface problems related to this research. Nevertheless it is interesting to note that even the earliest graphical scheduling approaches were based on a linear time-scaled representation (O'Brien, 1969).

2. Design issues

After presenting the functional requirements and the hardware configuration used, this paper identifies issues associated with user interfaces for device scheduling. Four alternative touchscreen-based user interfaces are described. We then report the findings from a usability test conducted on the three most innovative prototypes. Our conclusions are also based on the comments of more than 30 informal reviewers and on the feature by feature discussion of the interface.

The project had a highly practical orientation since this work was conducted in collaboration with an advanced technology company (Custom Command Systems Inc, College Park, MD). Custom Command designs and installs home automation systems which integrate entertainment, security, lighting, climate control, communication and other devices in affluent homes and offices. The company's designers provided the requirements for the user interface and the hardware, and commented on the designs.

2.1. FUNCTIONAL LIMITATIONS

The functional requirements for the three user interfaces are identical. A subset of basic scheduling tasks was identified. These standard tasks fall into four general classes:

(i) single action (turn OFF water at 9PM);
(ii) 1-day event with both an ON and an OFF time (turn the VCR ON at 9.30PM and OFF at 10.30PM on the same day);
(iii) 2-day event within a 24-h time period (turn the lights ON at 7PM and OFF at 1AM the next day);
(iv) multi-day event (turn the alarm ON at 10AM on the 21st and OFF at 6AM on the 30th). For simplicity scheduling is limited to a single device at a time.

An event can occur on any day so the user must be able to select the day and then set the ON and OFF times. Appropriate visual feedback must be provided, so that users can verify their schedules. Some editing must be supported to allow users to revise an incorrectly scheduled event.
Other issues include copying schedules, scheduling repeated events on different days or at regular intervals, editing schedules (Plaisant, Shneiderman & Battaglia, 1990) and scheduling devices that are more than binary.

2.2. TECHNICAL REQUIREMENTS

The control of the scheduler is through a touchscreen interface. The home owner sees the screen as a fixture which is almost flush-mounted into a wall or custom-built in the furniture or cabinetry. The touchscreen and all the home devices are controlled by an AT class personal computer. The colour graphical screen displays are implemented under MS-DOS in the EGA mode (640 × 350 pixels).

Touchscreens were selected as the hardware side of the user interface because the expected users are not necessarily familiar with keyboards, mice, or other more complex hardware interface devices. In addition to providing a natural method of interaction, touchscreens are easy to learn, rapid, have no moving parts, require less work space than other input devices and evoke a high degree of user satisfaction (Pickering, 1986; Sheer, 1988).

The Microtouch touchscreen used returns a continuous flow of coordinates with a 1024 × 1024 resolution which is smoothed and transformed to a 640 × 350 resolution. The continuous flow allows the dragging of objects and the use of a lift-off strategy for selection (Potter, Shneiderman & Weldon, 1988): when the finger touches the screen a cross-hair cursor indicates the exact coordinates read by the touchscreen. Only the lift-off of the finger activates "hot" keys or sets an object being dragged. This strategy reduces the error rates and allows the selection of targets as small as one pixel (Sears & Shneiderman, 1991) merely by sliding and rolling a finger (no stylus or zoom is required).

In Custom Command's current system, users first select a device to be scheduled and then are presented with the "standard" scheduling interface labelled with the device's name. It is the redesign of this standard interface that we will discuss next.

2.3. DESCRIPTION OF THE FOUR USER INTERFACES

The four interfaces described here do not exhaust the possibilities but raise the issues involved in the design of such interfaces. Only the central components of the interfaces are described. Descriptions of buttons used to return to the operating system or to reset or clear the interface are not considered central to the discussion here.

In our designs we tried to make the best use of direct manipulation techniques and also to take advantage of the common representations of time. The schedulers are centered around two objects, a calendar and a scheduling clock mechanism. The clock mechanisms are the most distinctive: a digital style day and time-setting device; two analogue 12-h clocks; a 24-h dial; and a 24-h line.

2.3.1. Digital scheduler

The digital scheduler (Figure 1) represents the day and time digitally. The date and ON time are displayed on the top part of the screen. The OFF time is displayed on the bottom part of the screen. Arrows are displayed under and above each digit and the month names.

Initially the screen appears with both ON and OFF set to the same default value
2.3.2. 12-h clock scheduler

The 12-h clock scheduler is shown in Figure 2. The screen is divided into two identical regions. The left side of the screen is used to set an ON time (or START) and the right one to set an OFF time (or STOP). Each scheduler consists of a monthly calendar, a 12-h analogue clock with two hands (similar to an analogue wrist watch), and an AM/PM toggle.

When starting, only the calendars and QUIT button are active. The clocks are grayed-out to indicate their inactive state. When a calendar is touched, a red rectangle is displayed around the day under the user’s finger. The lift-off strategy is used to reduce the error rate: the day is selected only when the finger is released, allowing users to drag their fingers until the red rectangle highlights the day they
want to select. The calendar displays the current month with adjoining buttons to access the previous and next months.

Once a day has been selected on either calendar, the corresponding clock becomes active which is indicated by highlighting the clock and adding hands to the clock face.

The hands are moved by touching the screen. Two strategies can be employed to move a hand. In the first strategy users select the hand they want to move by touching it with their finger; the hand is then dragged around the clock face to the desired position. If both hands are close together the initial touch point determines which hand is selected. The hour hand is selected only when the initial touch is inside the innermost part of the clock face.

The second strategy consists of directly touching the position where the hand needs to be moved. The numbers displayed around the clock are placed so that if users touch the number "3" the hour hand jumps to 3, and if users touch the number "45" the minute hand jumps to 45.

A toggle is associated with each clock to set the AM or PM. When touched, the toggle changes colour, and switches to the opposite value when released.

When designing this version our hope was to provide a simple and stable interface using a familiar time representation and making a clear on-screen separation of the two actions required to schedule an event (set the ON and set the OFF). Entering a new event is the only possible task. More complex functions like editing old events have to be handled by a separate utility not covered here, which does not add complexity to the initial scheduling but to the overall system.

2.3.3. 24-h line scheduler
The 24-h line scheduler (Figure 3) consists of a monthly calendar, two lines representing 24-h days, and the ON flags and OFF flags.

Initially the two lines are grayed-out as inactive, and no flags are available. Users select a first day by touching it on the calendar using the same mechanism as the previous scheduler. This first day appears on the top line. The line is now coloured. The graphics suggest the different times of the day by showing a sun in the middle, the moon at night and the length of daylight.

![Figure 3. The 24-h line scheduler.](image-url)
If necessary, a second day can be displayed to schedule some device over a night or over several days. If a third day is selected, the first is replaced and the latest 2 days touched are displayed always in chronological order.

Stacks of the available flags are displayed. To schedule an event, users select a flag by touching a flag source, and then drag it toward the time line placing it at the desired time position. For example, an ON-flag cursor appears just above users' fingers when they touch the ON-flag stack. The flag can then be dragged to any of the two lines. While the flag is sliding on the line, exact feedback of the time is displayed under the stack of flags. When the finger is lifted off the screen, the flag becomes attached to the line.

The periods where the device are ON are shown in red on the line. A flag already set on a line can be moved again for adjustment, or removed by dragging it away from the line. When a day is chosen by touching the calendar, the flags previously attached to it are redisplayed and can be edited.

A complete record of the scheduled events is also visible on the calendar. Thin red lines appear on the days in which events have been scheduled. For example, if a user places an ON flag on the 19th, and an OFF flag on the 24th, the numbers from 19 to 24 will be underlined in red. A CANCEL LAST button is available to remove the last flag set. Any flag can be removed by dragging it away from the line.

When designing this interface, the possible generalization to complex tasks was a major concern but some of us feared that the linear representation of the day might be confusing for potential users.

2.3.4. 24-h dial scheduler
The 24-h dial scheduler (Figure 4) was designed and implemented by Jeffrey Mitchell. It has a main window with a large calendar and a QUIT button. When a day is selected by touching the screen the select sound is emitted, the day is highlighted on the calendar, and a dial window appears, partially overlapping the calendar and the QUIT button. The dial window includes a 24-h dial with one hand, buttons labelled ON, OFF and CONTINUE or DONE.

To turn the device ON at a given time, users first set the hand at the desired position then press the ON button. Exact feedback of the time is given in the top
right corner of the window while the hand is being positioned. A green radius line is
drawn to mark the ON time. To turn the device OFF, users set the hand then press
OFF. A red line is drawn to mark the OFF time. The area of the dial in which the
device is ON is shown with a green arc connecting the two radial lines.

When both times are set, the DONE button is used to return to the calendar
window. If the event is longer than 24 h, the ON time is scheduled and then
CONTINUE is pressed. When CONTINUE is pressed the dial window disappears
and the calendar window is again active. A second day is selected from the calendar.
When the dial re-appears only the OFF and DONE buttons are active. Users set the
OFF time and press DONE to finish the multiple-day schedule.

This 24-h dial representation is at its best when scheduling an event starting one
day and ending the following day within a single 24-h period: for example, a user
can turn a device ON on the 29th at 9PM and then move the hand to 1AM on the
same dial and press OFF. The device will be ON for 4 h up to 1AM on the 30th.

The calendar gives overall feedback for the scheduled events by displaying small
dials on scheduled days. Events are displayed on the small dials by filling in wedges
of the dial with a colour that contrasts with the calendar background.

When designing this interface the readability of the screens was a major goal, as
well as offering an often encountered style of interaction with enforced sequentiality
(i.e. the users are guided step by step in their actions). Another goal was to have a
large calendar and large clock, thus leading to the need for overlapping display.

2.4. COMPARISON OF THE SCHEDULERS

The user interfaces can be compared along a number of dimensions, including: (i)
date selection, (ii) time selection, (iii) number of required touch actions, (iv)
precision, (v) feedback and (vi) sequencing and interaction style.

2.4.1. Date selection

Two selection strategies are used in the four user interface designs.

The digital interface uses buttons to increase or decrease the date displayed in a
textual manner. If the default values of the day and month correspond to the current
day, no action is required to schedule an event for the current day. Only a few
screen touches are necessary to schedule events in the near future. On the other
hand, the setting of a distant date can take up to nine touches in a 3-month range.
The use of the buttons does not require a high-precision screen touch.

Selecting a date from a calendar is a more direct selection process. Users directly
touch the desired day. The monthly representation of the time seems easier. Only a
single touch is necessary to select a day in the current month and a maximum of
three touches for a selection in a 3-month range. A weekly calendar could also be
used, but the paging would become laborious to reach a remote date (e.g. up to 12
touches could be required in a 3-month range). On the calendar the current date can
be shown, along with feedback about the events already scheduled. The top line of
the calendar displays the days of the week (Monday, Tuesday etc.) that could be
used for weekly events; for example, if Friday is selected, the event scheduled will
take effect every Friday.

Depending on the size of the calendar, more or less precision and care is required.
In the first two versions, the calendar is always displayed; therefore its size is
limited—each day is represented by a 0.5 cm² square. The use of a lift-off strategy is required to select a day smoothly without errors. In the 24-h dial version, which uses overlapping windows, the calendar can occupy the whole screen and either a land-on or a lift-off strategy can be employed.

The digital and 12-h clock versions present two calendars while other versions present only one. For schedules within a single day, displaying two calendars might be confusing because users have to select the same day twice; however, for events that start in one month and finish in another, two calendars are probably preferable.

2.4.2. Time selection
The user interfaces use four different representations of the of day: a digital clock, an analogue 12-h clock, a 24-h dial, and a 24-h line.

In the digital version, a numeric time is presented. Touching buttons increments and decrements the values. By having buttons available for each digit, the maximum number of touches can be limited to 14 touches to set a time. This representation is very simple, readable and precise.

On the other hand, this display does not give any natural feedback of the duration of the event nor of the relation to the current period with the other ones already scheduled. It does not show the actual state of the device being scheduled. A separate table is necessary to list the other events set for the same day, which means that editing or deleting events involves other mechanisms not discussed here. An AM/PM toggle has to be used if the common 2 × 12 h notation is used.

The other three representations of the time are analogue. The 12-h clock used in the second version is very attractive as a common time representation. It could be assumed that everyone using a scheduler knows how to read and set a time on this type of clock. Users quickly discover that the hands have to be turned to set the time, and the touchscreen interface offers all its power by allowing the users to turn the hands with a very easy finger gesture.

There are some difficulties with analogue clocks. When the hands are close together users must learn how to select one or the other. Also the two 12-h clocks showing the ON and OFF times do not give a clear image of the event duration, especially when the event overlaps more than one AM or PM period. Here, again, an AM/PM toggle is necessary and a separate table has to be used to see the times of the other events scheduled.

In the 24-h dial version, the dial is still an analogue clock but with a single hand. The 24-h representation avoids the AM/PM toggle which users are likely to forget as in the previous representation. Here the single hand is easy to select because there is no more need to discriminate between the two hands of a 12-h clock. The length of the event can be shown by filling areas of the circle, but several circles have to be used when the event covers several days. Several events can be represented and therefore editing is possible. Events can also be scheduled across 2 days within any 24-h period using only one dial.

The fourth representation of the time is a 24-h line. The image used here is one of an appointment agenda on which events are drawn as lines connecting the beginning to the end of an event. Here, again, no AM/PM toggle is necessary. A graphic representation of the day can help confirm the scale marked on the line. Ideally the length of daylight, the phase of the moon or even the weather forecast could be
suggested graphically. The length of the event can easily be read and multiple events can be shown on the same line. Only an extremely large number of events would overcrowd the line and require supplementary tools such as a magnifying glass. In our prototype only two lines are displayed simultaneously, but it is quite possible to display a larger number of lines allowing more complex tasks (like tasks that involve several devices or several days of the week). Another alternative would be an interface with only one line which could be expanded, contracted or scrolled to show the desired period in time.

2.4.3. Number of required touch actions
A simple performance model can be developed by counting the number of touch actions necessary to perform a scheduling event within a single month and to become ready to set another event. “T” stands for a touch and release, “D” stands for drag (touch an object—drag it—release), (≤max.) means several actions and the italic style marks actions performed only when the event covers several days.

Table 1 shows that the digital version could lead to a very large number of touches, even when using separate controls for each digit, unlike the 24-h line version which requires a very limited number of actions. Of course, dragging an object is a more complex action than pressing a button and involves better hand–eye coordination. More research would be necessary to compare the four solutions precisely.

2.4.4. Precision
The digital scheduler allows the user to easily set a time to the minute. Even greater precision could be attained by adding more digits.

In the 12-h clock, each degree of angle corresponds to 1/6 min of time while using the minute hand (30° for 5 min). It is relatively easy to set a time to the minute.

In the 24-h dial, since only one hand is used, more careful control is necessary. Each degree of angle corresponds to 4 min of time. It is relatively hard to set times to the minute (but possible when using a very large dial).

The 24-h line uses the whole width of the screen. One hour is represented by only about 1 cm, and we chose to give access to 10-min intervals only. Furnaces, air conditioning and many other devices do not require high precision in their

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scheduling and 5- or even 10-min intervals might be quite sufficient. If more precision was necessary, the 24-h dial and the line versions would need some additional mechanism to adjust the time.

2.4.5. Feedback
All four interfaces provide feedback on the currently scheduled event. Only the 24-h line and the 24-h dial interfaces provide schedule feedback for previously scheduled events. The large calendar associated with the 24-h dial version displays partially shaded circles on days when events are scheduled. It is easy to spot the days where events have been scheduled, and the reading of the times on the circles is simple if users remember that it is a 24-h representation. The main problem with this representation is the discontinuity of time: e.g. a single event overlapping the 12 midnight time will be represented by two separately shaded slices. The line scheduler shows a line on the calendar on days when events are scheduled. The position of the beginning and end of each line is proportional to the time of start and stop. Because the calendar is fairly small, it can be difficult to estimate the duration of an event or even to see it if the event is short. In order for them to be seen, very short events are given a minimal length on the calendar.

2.4.6. Sequencing and interaction style
The digital version and the analogue 12-h clock use two independent clocks to set the ON and OFF day and the time. Users can set all values in any order they wish. The OFF time can be adjusted first before the ON time and dates can be set after setting the times. This structure is limited to the simple type of events chosen for our study involving only ON and OFF states for a device. When devices have more than two states (e.g. ON, OFF and AUTOMATIC for a pool cleaning system), supplementary clocks will be necessary for each state.

The 24-h dial version uses a different approach. The order in which an event is set is fixed: first select a day, then position the hand, press ON or OFF, move the hand to the other time position, and press the OFF or ON button. Such a strict sequencing needs to be learned. The user is guided by the buttons which appear only when they can be used. Devices having more than two states can be handled by adding supplementary buttons. Shortcuts can also be provided with special buttons like “ALL DAY” or “ON for 1 HOUR”.

The 24-h line version uses yet another interaction style. Flags representing actions are placed on the line representing a day. Actions can be given in any order (OFF first, ON second). A relatively complex manipulation is required to pick a flag, drag it to the line, adjust the time and release the finger but it can be seen as a single continuous action. The use of the touchscreen gives a very smooth feeling of dragging flags on a white board. The same easy-to-learn manipulation is used to schedule an event as to edit or delete previously scheduled events: dragging a flag away from the line removes it, sliding a flag along the line changes its associated time. Special flags can be made available for special devices: 1-h flag for the lawn watering system, automatic mode flag for the pool cleaning, evening flag for the lighting system (Custom Command’s home automation system includes the possibility of having preset moods for the house. For example, the evening mood will turn lights ON, close drapes etc.).
The 24-h dial version uses the overlapping technique to display the dial. This technique allows the designer to display a very large calendar as well as a large 24-h dial, thereby making the selections easier. It also makes it clear that the first task is the selection of a date since no clock is yet displayed. On the other hand, users must indicate their need to go back to the calendar by touching either the DONE button or the calendar itself without really making a selection. The real advantage of the overlapping technique is that it would allow the use of smaller displays. For example, the dial can completely cover the calendar if necessary. Similarly, the 12-h clock or the 24-line(s) could overlap or temporarily cover the calendar.

3. Usability evaluation

We conducted a formative usability evaluation with two strategies. Fourteen novice subjects were given a benchmark set of tasks and were videotaped using a thinking-aloud approach. We also asked knowledgeable colleagues, graduate students and visitors to our laboratory to review and comment on three of the designs. Because our primary goal was to explore innovative user interfaces the digital version was not considered in the usability evaluation. The use of digital representation is well known but can be tedious and difficult to set. Digital VCR scheduling is known to be confusing and frustrating (Nemly, 1989).

The novice subjects were videotaped while learning to use the interface and while performing the same set of scheduling tasks with the three user interfaces. Subjects used the schedulers in random order with two or three subjects assigned to each of the six orders. When the subjects completed the tasks their comments and preferences were solicited.

The usability test was conducted in two steps during the fall of 1988 and the spring of 1989. Among the 14 subjects (five women and nine men) involved in this test, five were recruited from a group of retired university employees who regularly volunteer to participate in such university studies. This older population was thought to be more representative of owners of home control systems than groups of students often recruited for such studies. The other subjects were part of the University and Custom Command Systems non-technical staff with ages ranging from approximately 30 to 60 years.

When the subjects arrived in the laboratory, they were invited to sit in front of a touchscreen which was placed on a normal desk. The video equipment was placed behind them. An experimenter sat on the side, gave very brief demonstration of the prototypes and read each task aloud. The experimenter checked that the subjects completed each task successfully, solicited comments and filled in a form as tasks were performed. Each subject used the schedulers for a total of approximately 40 min. Typical tasks were: "Schedule on ON time of 8.15PM and an OFF time of 11.40PM on the 2nd" or "Schedule the device to turn on at 11PM on the 5th and OFF at 1 AM the following day."

The goal of the test was to understand advantages and disadvantages of each aspect of the designs, to identify the difficulties users had while using the schedulers and hopefully to select the best design to be implemented by Custom Command Systems.
4. Results

We will first discuss the use of the calendars, then present the observations made for each of the versions.

4.1. ABOUT THE CALENDARS

As foreseen, all users identified the calendars as calendars and used them properly. The 24-h dial version’s larger calendar was appreciated as being more readable. On the other hand, this last version did not use the lift-off strategy to select a day (the initial touch triggered the date selection) and despite the larger size of a day square, errors occurred and users had to return to the calendar to re-enter the proper date. This did not happen as much in the other versions, showing again the advantage of the lift-off strategy (Potter et al., 1988). Approximately one-third of the subjects and many informal reviewers remarked on the ease and smoothness of selecting a day on the calendar (corresponding to a rectangle of about 0.5 cm²). Only one subject had some temporary difficulties mastering the lift-off technique. Users also suggested the addition of a “today” button or a default positioning on the current date.

4.2. ABOUT THE 12-H CLOCK VERSION

As foreseen, users identified the clocks properly and were not surprised to have to turn the hands of the clock. Two subjects even avoided turning hands backward (to avoid breaking them?). Users tended to forget to set the AM/PM toggle properly, thereby scheduling the event at the wrong time!

Approximately one-fifth of the subjects and informal reviewers did not realize that they had to choose the same day again for the OFF time. Of course it would be possible to set the stop day default value equal to the ON day, but this might lead to unwanted schedulings of OFF time when users only wanted to schedule an ON time and do not notice that an OFF has been set automatically.

When the two hands are close together, it is difficult for most of the subjects to reliably select one or another. The rule “use the inside for the hour hand and the outside for the minute hand” is not quite natural enough and needs to be remembered. A larger clock would help but this problem will always remain.

Early reviewers noticed that they would lose the control of the hand being turned when their finger would move outside the clock border. This problem was solved by keeping the control of the hand until the finger was released, even if it had moved out of the clock. The initial touch inside the clock indicates which hand is being positioned and the finger can move away from the centre and set the hand with increased precision. This mechanism would also allow the use of much smaller clocks.

The AM/PM toggle was located as far as possible from the clock to avoid unwanted touching and moving the close-by minute hand while switching the toggle. Nevertheless, unintended touches of the minute hand occurred, sometimes unnoticed!

4.3. ABOUT THE 24-H LINE VERSION

The linear representation did not seem to surprise anyone. Three subjects and many reviewers commented on all the information that could be displayed on the line (e.g.
the current moon phase, the weather forecast, length of daylight etc.) and expressed positive opinions of that representation.

The AM/PM distinction was easily perceived. The presence of simple graphics such as the sun in the middle of the line allowed users to recognize AM and PM correctly without any additional labels.

The principle of dragging flags on a time line seemed to be natural. No subjects were confused. Two subjects expressed their great satisfaction with manipulating the flags. Some slid the flags around the other objects (like the sun or the top line), or brought the flag back to the corresponding pile when removing it from the line.

Initially a strong "gravity" effect was used to keep the flag attached to the line. This effect had been installed to enable greater precision by pulling up (for +) or down (for -) once the flag was on the line. But users felt they did not have good control of the flag which did not always closely follow their finger. This strategy also made it very difficult to move to the bottom line since the flag would "stick" to the top line before jumping to the bottom line. This strong gravity was quickly redesigned. The gravity pulling the flag to a line is now only active when the finger is released within 0.5 cm of the line.

The possibility of reselecting a flag on a line to move or remove it was installed immediately after the initial reviews, to respond to the great demand. This improvement and the suppression of the gravity made an obvious difference in the way subjects naturally handle the flags.

Approximately one-third of the subjects expressed their confusion about the presence of a second line. Most of the tasks required only one line and subjects were surprised to see still the time line used for the previous task when they called a new day time line. This confusion may be linked to the laboratory environment for which subjects do not expect a task to have any permanent effect, while we expected that users would find it re-assuring to still see the effect of their previous schedulings on the screen.

Subjects complained that they had to look under the stack of flags to read the time corresponding to their current position on the line. It would probably be preferable to display the digital feedback near the flag being adjusted or even on its label.

4.4. ABOUT THE 24-H DIAL VERSION

As discussed earlier the large size of the calendar was appreciated.

The strict sequencing of the interaction had to be described repeatedly to subjects, who often seemed to be searching for their next step. But they said they would probably remember the sequence if they used the system enough.

Many contradictory comments were given about the labeling of the buttons (DONE or CONTINUE or CALENDAR). Subjects were uncertain about how to cancel or modify an event. Several persons remarked that the clock could be made larger to give more precision, and more space could be left between the clock and the buttons.

Before the beginning of the test the clock had been labelled with $2 \times 12$ h, AM on the right, PM on the left. Surprisingly, many reviewers said they would greatly prefer the 24-h time notation for its clarity. We then tried the 24-h labelling for the
test. A quarter of the subjects complained about it, some seemed to be calculating the number to reach, demonstrating that the 24-h notation is not well known in the US. Each notation clearly has its detractors and a scheduling system should offer both notations as options.

4.5. ERROR OCCURRENCE

We only considered as errors unnoticed errors (e.g. an event which was scheduled for an incorrect day or an incorrect time of the day). No errors at all were made on the date selection. Errors occurred in the two 12-h clock version when the AM/PM was forgotten and in the 12-h clock and 24-h dial versions because the hands were moved accidentally in an attempt to select a button (like AM/PM, ON, OFF, DONE). All other errors were found and corrected immediately without intervention of the experimenter.

Of course many tasks were performed imprecisely (e.g. 10.35 or 10.39 instead of 10.40).

4.6. PRECISION ISSUE

Subjects always felt they had performed the task correctly, but in fact subjects very often did not try to set the time exactly at the value asked in the scenario. For example, if asked to start a furnace at 5.10 they considered it correct to start at 5.15. On the other hand, once all bugs where fixed, all negative comments heard were related to the difficulty of precisely adjusting the time. Some users, including about a quarter of the subjects of the test tried very hard to get the exact time (personal differences, or was it the only challenge left?). Unfortunately our prototypes were intended to test the basic concepts and the fine-tuning mechanisms had not been refined. A stabilization of the touchscreen would improve the precision (Sears & Shneiderman, 1991) to allow the selection of 5-min intervals on the line (or 10-min intervals on a quarter size display) and many other techniques are possible (a magnifying glass effect, + and − buttons, scale stretching etc.). Fortunately, practical home control situations do not always require much precision. The few devices that do will need a customized tuning method (e.g. a VCR to the minute, a microwave to the second).

4.7. EVALUATING THE QUALITY OF THE FEEDBACK

Subjects were asked to perform tasks that were clearly independent from each other and there were no risks associated with a scheduling error. In a real situation, users of the scheduler are more likely to want to verify their work more carefully and also review it at a later time. This testing cannot give a complete assessment of the feedback quality. For example, the 12-h clock version does not allow the user to verify the events already scheduled yet none of the subjects remarked on it. Several of our reviewers commented on the fact that the pie-shaped feedback given on the calendar of the 24-h dial version could be easily misinterpreted because of widespread use of the 12-h scale. Additionally a discontinuous feedback is given (with several circles) when an event extends over several days.
**Table 2**
**Overall ratings**

<table>
<thead>
<tr>
<th></th>
<th>12-h clock</th>
<th>24-h linear</th>
<th>24-h dial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average point per task:</td>
<td>3.45</td>
<td>2.93</td>
<td>3.58</td>
</tr>
<tr>
<td>(1 = easy 10 = difficult)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of times the version</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>was selected as first choice:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(one subject did not choose)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.8. OVERALL RATING OF THE PROTOTYPES BY THE SUBJECTS

Despite the small number of subjects, a wide range of personal preferences was observed. Each version was rated highest by some subjects. After each task we asked the subjects to grade the difficulty of the task on a 1 to 10 scale (1 being easy and 10 being hard). We also asked the subjects which version they would choose if a similar system were installed tomorrow in their house. Table 2 gives the values and results.

These numbers correspond to overall ratings. We see that each version had its defenders. Our observations also showed that none of the versions was completely rejected. In this test, the precision attained seemed to be an important criterion in the overall grading of the three versions. We also saw that subjects did not always prefer (select as their first choice) the version that they rated as easier.

No significant conclusion can be drawn from this Table and our final recommendations to Custom Command Systems were also based on the comments of additional reviewers and potential extensibility of the design.

4.9. OTHER ASPECTS

When asked, none of the subjects expressed any negative judgment against the general screen designs and colours. Nevertheless we know that the choice of the right colour is still a challenge. What is the best colour for ON? We also feel that the screen of the 12-h clock version is too crowded with its two calendars, two dials and two toggles, that the calendars should preferably be moved to the top left corner of the screen and that, in general, every object should be made larger.

5. Discussion

5.1. ABOUT THE USE OF THE TOUCHSCREEN

Most of the touchscreen applications encountered today still use large “button-like” selectable areas. The development of our three schedulers was an opportunity to explore new touchscreen strategies with increased use of dragging or sliding movements (Sears, Plaisant & Sheiderman, 1991). For many users, dragging objects feels better than pressing buttons on a touchscreen. Turning the hands of a watch or sliding a flag provides a very nice feeling to the user and it is one more step towards direct manipulation. It would be interesting to compare the ease of controlling rotating or sliding objects with a touchscreen and with a mouse.
5.2. ABOUT THE SCHEDULERS

The 12-h clock was initially implemented assuming that no-one would have difficulty understanding how to use it. Because it has two hands, it is more precise and selecting a minute is quite easy. Nevertheless we observed that its use is not as easy as we hoped. The rule allowing users to select a hand when both hands are close together is not obvious and the limited size of the clock brings more difficulties (a very large clock may solve the problem of discrimination between hands). The main problem of a 12-h clock is that the AM/PM is too easily forgotten.

A 24-h representation (linear or circular) has many advantages: it solves the double hands problem, only one mark is enough to specify a time, several events can be shown on the same day, the length of the event is readable. But the 24-hr dial lacks precision and an additional tuning technique has to be used: a good stabilization of the touchscreen (Sears & Shneiderman, 1991) or some tools like a zoom, + and − buttons or sliders, or a very large circle. The circle representation is well-adapted to the scheduling of events overlapping 2 days, but the lines easily allow a larger number of days or devices to be represented on the same screen, making it a good candidate for complex tasks.

Another important issue is the interaction style. In the 24-h dial version the chosen sequencing of action is fixed and has to be learned (first set the hand, then press ON etc.) and users needed to be reminded of the right order. By comparison, the manipulation of the flag on the line is a single and direct action. The reduction of enforced sequentiality seems to be a desirable design goal (Keil-Slawik, 1991).

The line version also includes the editing and cancelling of previous events at no increase in the interface complexity, unlike the 12-h or 24-h dial versions which would need additional developments to include these possibilities.

In the 24-h dial version, the use of overlapping objects allows larger objects that are more visible and easier to select. It also makes it easier to understand what has to be done when only a calendar is visible. On the other hand, when an error has been made (e.g. selecting the wrong date), it is harder to correct because users have to remove the overlapping objects. No general recommendations emerge from the literature but we favour the non-overlapping designs.

6. Conclusions

Each of these versions has its strengths and weaknesses. The usability test showed that each of these versions can be easily used. Contrary to our initial expectations, the 12-h clock version was not the easiest to use and was the only version where serious errors occurred. The limited number of subjects in the usability test does not produce statistically significant results but our global experience with the three interfaces during the test and with the numerous other users of the prototypes makes us believe that a scheduler using lines and flags is a promising direction. It uses a simple and understandable concept and requires few touch actions. It also has the flexibility for additional functions like the scheduling of more complex devices having more than two states, multiple-day display, editing etc.

It is clear that complex and novel graphical user interfaces require substantial usability testing in order to assess which factors are best for a given task. It is also
apparent that the comparison of the user interfaces serves less to select a single interface than it does to highlight the differences and suggest further improvements.

Only simple scheduling tasks have been considered here. This work is also a platform for the study of more complex tasks like the scheduling of several devices simultaneously, repetitive events, creation and scheduling of macro-events etc. Besides being useful in a home control system, easy-to-use scheduling interfaces could also find applications in professional environments like an office, conference room, audio–video room control, hospitals or industrial process control.

7. Update

Since the original writing of this paper, the 24-line scheduler has been integrated into Custom Command System (Figure 5) and is in use in houses. The process of integration and extension of the original design to repetitive scheduling and other parts of the system has been described in Plaisant et al. (1990). A video demonstrating the three prototypes is also available (Plaisant & Shneiderman, 1991).

Jeffrey Mitchell designed and implemented the 24-h dial version and participated in the usability evaluation. We would also like to thank all the members of the Human–Computer Interaction Laboratory for their useful suggestions as well as Jim Battaglia and Hank Levine from Custom Command Systems Inc for their participation in the design of the interfaces described in this paper. We appreciate the support of the Maryland Industrial Partnerships program and Custom Command Systems Inc in providing partial funding for this research.

References


