SUPPORTING COLLABORATIVE FIELD OPERATIONS WITH PERSONAL INFORMATION PROCESSING SYSTEMS

S. Guerlain, J. Lee, T. Kopischke, T. Romanko, P. Reutiman, and S. Nelson

Honeywell Technology Center, Minneapolis, MN

ABSTRACT

This paper describes a two-year research project to develop a Personal Information Processing System (PIPS) solution for the roving industrial field operator. Our PIPS system is comprised of 1) an RF network to deliver wireless, digital information, 2) a wearable computer for delivering web-based information (the hardware is a two-piece system comprised of a belt-worn NetPC, attached via a curly cable to a hand held unit with a mouse/display device combination), and 3) software applications that provide added value in the field. Unique challenges in designing such a system for this environment include: 1) having good RF coverage in an environment with so many metal structures, 2) having an intrinsically safe hardware system that provides a lightweight, low cost solution, and 3) having software that is compatible with the wearable system and supports collaboration in the field.

INTRODUCTION

Honeywell has a long history in the development of miniaturized displays, custom micro-electronic hardware, and wearable, portable devices, primarily to support military applications. Prototype and production systems over the past 10 years have been developed primarily out of the Honeywell military avionics division that are helmet-mounted, wrist-mounted, backpack-mounted, binocular, monocular, see-through, see-around, supporting night vision, or visible in bright ambient lighting conditions. More recently, Honeywell researchers have been trying to move these types of technologies into the specialized commercial market of supporting the roving refinery operator in the petrochemical and oil and gas markets. Much of the needs in this market are similar to the military requirements, namely, the systems must be ruggedized, and able to handle harsh environmental conditions. Less similar are the social implications of introducing such innovative technological solutions into an environment where the work force is primarily union-based, and personal routines are widely varying, yet well-established, current communication is primarily face to face or via two-way radios, and information tracking is scattered and largely paper-based.

Our goal in trying to adapt PIPS (personal information processing systems) into the refinery field operator environment is to take a user-centered, systems-based approach, providing a solution that fits the needs of the environment, the individual workers, and provides added value by providing an infrastructure that supports collaborative field operations. The solution we have been developing can be broken down into three related parts:

1. Develop an RF network infrastructure to support wireless, digital communications
2. Design a wearable hardware system customized to the refinery operator's needs, and
3. Develop software tools and applications that are personalized, intuitive, customizable and support collaboration in the field.

These three pieces of the puzzle form a kind of three-legged stool. Correspondingly, we had three design teams working somewhat independently towards the common goal of designing a solution that worked well together. The project proceeded in two stages. In Year 1, we developed a proof-of-concept first generation system. In Year 2, we developed a more complete package worthy of field test in a refinery environment. This paper will describe the design goals, actual designs, and preliminary evaluation results from internal as well as a field evaluation of our PIPS solution.

YEAR 1: A PROOF-OF-CONCEPT FIRST-GENERATION SYSTEM

Our first-generation system was designed with the goal of developing a proof of concept system to show to potential customers. Early prototypes of the wearable hardware consisted of a commercial-off-the-shelf (COTS) belt-worn Windows95 computer combined with either a hard hat-mounted monocle display device (see Figure 1), or a hand held unit (called the Eyewand) that combines a miniaturized projection display and a three-button user input device (see Figure 2). Focus groups with field operators led us to eventually focus on the hand held unit, as field operators were reluctant to have a head-mounted system that could obstruct their vision (even though we had designed a flip-up mounting), that added weight to their head, and was likely to get bumped endlessly as they walked under obstructions in the refinery environment.

Insert Figures 1 and 2 here

Wearable and tablet computers are typically plagued by limited screen size and/or user input challenges (Smailagic and Siewiorek, 1996). A miniature projection display design has the advantage of a high-resolution display in a very small package. Our first-generation Eyewand had 640x480 (VGA) resolution, and our latest models are 800x600 (SVGA) resolution. Having this type of resolution allows us to design fairly typical desktop size user interfaces, important in a refinery environment for being able to display sufficient information (diagrams, schematics, and procedures). However, how to navigate through the software and perform data entry tasks is another question. By doing away with the helmet-mounted monocular design and adopting the handheld Eyewand approach, we were able to incorporate a user input device into the same hardware as the display device. We wanted the input device to be easy to use while walking around the refinery, and to have software that was simpler and easier to navigate than a full-up desktop type of an environment. We were reluctant to believe that a direct manipulation pointing device would be easy to use while walking around, and felt that a mouse on a hand held unit provided excessive functionality at the expense of ease-of-use. Thus, the initial design of the Eyewand had three buttons, which we mapped to Up, Down, and a multi-function Enter button. Although we eventually abandoned this approach in favor of using a direct manipulation pointing device (a force-joystick “eraser head” type of mouse), the software user interface scheme we developed may be of interest to others who plan to use this type of a user input device. Further, it is useful to talk about what we learned in the process of designing for the original three-button configuration, and the reasons for our eventual abandonment of this approach. Our experiences demonstrate the challenges that the mobile computing community faces when venturing outside the desktop model of computing.

Our first-generation software was a prototype in that all the screens incorporated “fake” process data, personnel information, and procedures. At this stage, we assumed the eventual presence of an RF network for delivering “live” information, such as process data, to the device. Although our data was fake, the software navigation was live and linked to the three-button Eyewand, so that we could demonstrate and test the hardware/software combination to potential end-users.

It was a considerable challenge to design a software user interface that was entirely driven by three buttons. However, after much thought and some trial and error, we were able to design and prototype (in VisualBasic) a fairly functional, easy-to-use software navigation scheme. All navigation through the system is done either using a pop-up menu to navigate between displays, or follows a tree structure or a circular structure (explained below) to navigate within an application screen. Pressing and holding the multi-function Enter button serves to call up the pop-up menu. Once the menu is displayed, the user can navigate up and down the menu by use the Up and Down buttons on the Eyewand, and select an option by pressing and releasing (clicking) the Enter button.

The pop-up menu that displays when the user presses and holds the multifunction Enter button is divided into three parts (see Figure 3). The center of the menu displays a Cancel option, which is the default position when the menu is displayed. Selecting this option serves to Cancel the menu display, in case the user called up the menu by accident or decided to go back to the screen that he was working on. The menu items displayed above the Cancel option consistently display options for navigating to the major types of applications available. For example, in our prototype, the user can navigate to Personnel, Maintenance, Process data and Email. The menu items displayed below the Cancel option are context-sensitive: the options displayed are relevant to the task that the person is working on when he calls up the menu. For example, while looking at a process control screen, the pop-up menu has context-sensitive options for viewing schematics or trends of the data. If no context-sensitive options are available when the user calls up the menu, no options are displayed in the bottom part of the pop-up menu.

Insert Figure 3 here

Navigating around a display with just the Up, Down, and Enter keys is achieved primarily using a tree-based user interface control. For example, in the Process Data application, the main screen uses a tree structure as a means to navigate to groups of data that are related to pieces of equipment, such as the Compressors, Towers, Furnaces, etc. The user can move up and down the tree by using the Up and Down buttons on the Eyewand, and collapse and expand the tree by clicking the Enter button on the Eyewand. If at an end node, clicking the Enter button serves to perform the default option for that item. For example, when viewing a procedure step as an end node in the Procedures screen, clicking the Enter button serves to check off that step.

An alternative type of navigation within an application window is what we call “circular navigation”. For example, using the context-sensitive menu options available when viewing process data, one can navigate to trends of the data and schematics that show the data in a process flow diagram type of a format. These types of screens do not display a tree structure. Rather, these subscreens are specific to the process data being displayed on the main screen when the menu option was called up. For example, if one selects "View Schematic" when looking at the C-3 tower process data, the schematic displayed is relevant to the C-3 tower. Once viewing the schematic, the user can "circle around" the display in one direction by continuously clicking the Up button, or circle around the display in the other direction by continuously clicking the Down button. When viewing trends of the data, the trend related to one point fills an entire screen, so pressing the Up or Down buttons cycles the user through a set of trends related to the group of points in question (in this case, the six points related to the C-3 tower). Navigating back to previous screens is performed by using the context-sensitive menu, which now has options for closing the currently viewed screen.

This prototype hardware/software system was evaluated by refinery operators and engineers from several national petrochemical companies. Results of the study showed that navigating through the user interface in this manner was remarkably easy-to-learn and easy-to-use (Reinhart, Guerlain, and Whllock, 1996b). Novice computer operators unfamiliar with the Eyewand could pick up on how to use the system very quickly and had no problems manipulating the input device or navigating through the system. Furthermore, quite a wealth of information could be logically organized into screens and found easily by the user. Although it originally was a huge challenge to design a navigation scheme with just three buttons, we were surprised at the amount of functionality and flexibility this final navigation scheme afforded. We were also pleased that our original design goal of having an extremely easy-to-use, simple operating system was realized.

One major disadvantage to this system is that it afforded little data entry beyond logging on and off and signing off steps. An even more significant disadvantage from the customer's point of view was the non-standard nature of the software. Customers wanted to be able to easily port existing information and use existing software development tools to customize the information delivered to their field operators. The need to format data into the structure required by this navigation scheme (and the need for having development tools available to do so) made the system too customized and proprietary for the customer base to want to adopt it. Thus, the tradeoff between: 1) Having an extremely easy to use user input device/software navigation for the field operator, and 2) Ensuring flexibility and customization opportunities by the customer site, fell on the latter side, and led us to abandon this hardware/software combination, and instead go to a more traditional, point and click (direct manipulation) type of a user interface scheme for our second generation system.

YEAR 2 - A SECOND-GENERATION, FIELD-TESTABLE SYSTEM

We were successful enough in our first year to warrant a second-generation design activity, with the goal in the second year of developing a complete enough system to be able to run a field test in a refinery environment. The field test required us to develop and install an RF network, develop a hardware platform that passed intrinsic safety requirements of the refinery industry, and develop actual software applications that were linked to live process data, delivered real procedures, and were configurable by the customer site and customizable by the end-users.

We made an early decision to make our second-generation system a web-based system. The reasons for this were many, but were primarily driven by the desire to have a “thin client” NetPC as our wearable computer, rather than have a full-up Pentium-based computer. This would enable us to design a smaller, lighter weight, lower cost system with better power management and a longer lasting battery life. A second advantage of using a web-based system is that it provides an existing infrastructure for collaborative operations. By linking our system into the corporate intranet, we have the advantage of personnel being able to log on to the field operator’s web site throughout the refinery, to see the current status of activities, and interact with the personnel through the web site if necessary (such as by scheduling tasks). Finally, designing for the web is becoming quite commonplace, and thus provided us with a more open development platform, as was requested by the customers at the end of our first year of effort.

Our test site consisted of four functionally related “units” at a petrochemical refinery. (A unit is a logical sub-system in a refinery). These units encompass a 1000’ x 1000’ footprint and have structures on them that are up to 13 stories high. The units are run by a shift team (there are 3 shifts per day) comprised of 11 people: one shift supervisor, two central control room operators, two outside chief operators, and six field operators. Routine field operator tasks include conducting rounds, inspecting equipment, gathering routine maintenance data, taking samples, and preparing equipment for maintenance. Non-routine tasks can include activities as extreme as fire fighting. Operators often have to climb ladders, and routinely carry a flashlight, two-way radio, and hand tools. They wear fire-retardent protective coveralls, hard hats, earplugs, safety goggles, and steel-toed boots.

We intended to primarily support the six field operators in this field test, providing them with wearable hardware and access to procedures and process data, although it was also intended that the chief operators and central control room operators (as well as others in the refinery, such as maintenance personnel and engineering) would benefit by having access to the web site from anywhere in the refinery to get an overall view of the field operations, as well as benefiting from having on-line data logging, and a centralized, on-line repository for procedures.

As mentioned in the introduction, we had three design teams working on the RF network, wearable hardware, and application software, respectively. There were unique challenges that each team had to face to meet the design constraints of the refinery environment. The major challenges for each category were:

1. How to come up with an RF network design that provides continuous, full coverage with adequate bandwidth in an environment so densely populated with metal pipes, structures, and obstructions

2. How to design wearable hardware acceptable to refinery operators (lightweight, unobtrusive, easy to use, with good power management and meeting the needs of the intrinsic safety requirements of that industry)
3. How to design software that provides added value over existing paper-based solutions, and fits within the bandwidth limitations of the RF network and is easy to use and functional given the wearable hardware input device constraints.

THE PIPS RF NETWORK FOR INDUSTRIAL APPLICATIONS

Design Goals

The primary goal of the RF Network was to provide a digital wireless Local Area Network (LAN) to support data applications associated with the mobile workforce at the refinery. Mobile workers needed seamless connectivity in the area in which the demonstration was to be performed. We wanted to maximize the transmitted data rate with the constraint of maintaining connectivity in the harsh RF environment presented by the obstructions of the oil refinery. Oil refineries present a difficult communication environment due to the large quantity of pipes, metallic structures and reinforced buildings. The RF communication coverage not only had to support activities on the ground covering an area of 1000 x 1000 feet but also up on top levels of 13 story structures. Anticipated number of users was limited to less than 10 for the demonstration.

Design Implementation

The general structure of the LAN consists of three main items:

1. <u>A main access point</u>: Electronics which function as an interface between the wired network and the transmitted RF signal; the access point converts the data from Ethernet into packet data for wireless transmission (and vice versa).

2. Several repeaters: Repeaters are access points configured to just re-send the data out through the antenna and not the Ethernet port, thus repeating the signal. Their function is to extend the range of the wireless communication link.
3. Wireless LAN adapter: This is the modem electronics integrated with the body-worn computer allowing the mobile worker to receive and transmit data through the antenna.

One main access point was used as a wired link back to the main server. Additional repeaters were set up to ensure a link could be made between a mobile worker and the main access point from any location in the demonstration area. Workers can be located in very shielded areas such as metallic elevators, metal sheds which protect pumps, generators, etc., and dense populations of pipes.

Implementation of the wireless LAN focused mainly on 2.4 GHz Industrial, Scientific, and Medical (ISM) frequency band because of the bandwidth for data transmission and a license-free operating frequency. The wireless LAN hardware operates as a Direct Sequence Spread Spectrum (DSSS) at a data rate of 354K bits per second. This is lower than a maximum of 2M bps to allow for greater range. Range of communication is heavily influenced by the amount and type of obstruction between the antennas as well as the gain of the antenna. Maximum transmit power was 100 mW. This application required omnidirectional performance, so the gain of the antennas was less than 6 dB.

THE WEARABLE HARDWARE

No existing wearable hardware system meets the intrinsic safety requirements of this industry, is sufficiently lightweight and wearable, and has the built-in RF modem needed for our RF infrastructure design, which is why we were led to developing our own system to meet the requirements of this industry. Our current design has the wearable hardware split into two modules: a separate processor/rf computer radio battery box umbilical'd to an I/O (input/output) display system (see Figure 4). Until future technology improvements in batteries and component/packaging miniaturization allow complete integration of all these modules into a sufficiently small and lightweight package, in our view this split design with the computer/radio/battery belt borne and the I/O system either hardhat mounted or hand held, offers the current best wearable convenience and comfort for a typical hardhatted industrial worker.

Insert Figure 4 here

The Eyewand I/O System

There are several fundamental decisions to make in designing a body-borne I/O system for an industrial worker. Major display decisions include:

1. Direct view vs. optically magnified miniature display source. Direct view displays require a fairly large footprint laptop/tablet design. For our particular target industrial users, such as roving oil refinery workers, we found a strong preference for as small a display format as possible. Direct view laptop/PDA (personal digital assistant) format devices are just too large and bulky to be willingly carried by these workers in the routine conduct of their field tasks. Direct view displays also present issues with resolution, color, and ambient viewing contrast.

2. Hard-hat mounted vs. hand-held devices. In our study of typical user tasks and hardware design preferences, we also found that while indeed there are several field tasks that require the hands-free operating mode enabled by the hard hat mount design, there was a strong preference not to have any extra head-borne weight if at all possible, since just the hard hats themselves were the source of complaints about neck fatigue during long work shifts. Hence, for this initial work, we chose to concentrate most of our resources on hand-held designs which could conveniently incorporate software navigation devices (i.e., integrated mouse and select buttons) in the same package.

3. See-through vs. see-around designs. Having settled on using miniature flat-panel displays (FPD's) with magnification relay optics as the design approach of choice for our applications, there are several ways the optics could be implemented. For example, by including an optical beam splitter in the

design, the displayed image could be overlaid on the direct see-through image through the beam splitter. The alternative of course is simply to route the image from the display directly to the eye, resulting in a so-called see-around design. The advantage of the see-through design is that it allows direct comparison (even 1:1 geometric registration as appropriate) of a scene vs. displayed image, which may be useful for tasks such as setting complex switch boards or wiring harness layout. A major drawback to this design is that in order to maintain display "viewability" as measured by contrast ratio, much more display brightness, and hence shorter battery lifetimes, is required for the see-through vs. the see- around implementations for identical ambient lighting conditions. In this work, since the application suite does not require overlay capabilities, we chose to focus on the see-around approach.

4. Miniature Flat-Panel Display Technology. There are several rapidly evolving FPD technologies available for use for man-portable displays including AMEL, OLED, FED, and AMLCD. Each have their advantages and disadvantages and vary greatly in their degree of technology maturity. Since we are focused in this work primarily on commercial applications, we chose AMLCD devices since they are the most readily available commercial-off-the-shelf (COTS) miniature FPD display device on the market, driven by the large 35 mm optical format projection display markets (both for data projectors and for the so-called convergence large screen TV/computer display markets).

So, to summarize, this work concentrated on the design and development of a hand-held monocular see-around display device with integrated mouse, using a COTS miniature 35 mm format AMLCD display. We call this device an Eyewand.

The design of the Eyewand was a collaborative effort involving mechanical, electronic, optical, and industrial engineering expertise, as well as human centered design (ergonomics) experts. The case shape was designed for cold weather glove "holdability", with a top-mounted, integrated single button mouse (forefinger button/middle finger pointer actuation). A recessed thumb well includes a safety switch which prevents accidental mouse actuation during holstering (serving as part of the display's power management system).

The miniature FPD is a monochrome COTS device, with 800 x 600 pixels (SVGA), using a cold cathode-type fluorescent backlight . With the proper polarizers and drive signal format (see Table 1), this device is capable of 256 gray levels and 200:1 contrast ratio performance. With this optics and the backlight described above, the typical luminance at the viewing eye is a minimum of 50 ftL. A single 8-layer surface mount board was designed to drive the display using the display chip set as well as incorporate a mouse pointing device.

Insert Table 1 here

A single shielded 11 conductor curly cable with a standard 15 pin D PC display connector completes the Eyewand system. Total assembly weight with umbilical cord is 453 grams, or just under one pound.

The Wearable Processing System

The requirements for the portable processing system were primarily driven by the software, I/O devices, and the human factors of the operator. The following preliminary hardware specifications are listed in Table 2.

Insert Table 2 here.

Typical wearable computing systems provide the latest Pentium technology, hard disk storage, PC Card interface, and the typical laptop battery life of 3 hours. The design team evaluated current wearable products on the market and concluded that these products did not meet the design specifications:

- Processor performance was excessive for the application
- Hard disk storage was not necessary; the web pages could be cached in RAM and no application storage is required on body

- Size and weight of the devices were large and cumbersome
- Power requirements would not provide the 8 hour continuous use
- None were UL1604 approved

Thin Client Approach. The application required a robust RF LAN infrastructure to provide the web browsing capabilities. With the RF LAN structure, the design team turned to a thin client processing approach using a COTS PDA processor. The advantages of the PDA processors are their low power consumption, and firmware operating system's availability to eliminate the hard disk storage. Further, they meet the size and weight requirements for the application. Figure 5 is a block diagram of the wearable processing system.

Insert Figure 5 here

The critical issues in the thin client approach were the performance and availability of the Java Virtual Machine (JVM) and Java-compliant web browser on the PDA processor. There were numerous firmware Operating System (OS) vendors who offered JVM for their targeted hardware systems, but there was only one that advertised a Java-compliant web browser necessary for the Java applications. This firmware OS then drove the hardware platform for the PDA processing system. Most firmware OS vendors, including Microsoft's Windows CE system are working on Java compliant browsers but had nothing promised in the time frame required.

Once the architecture was chosen, the hardware development team worked with a major PDA integrated circuit (IC) manufacturer. The IC manufacturer was eager to assist in our development application and offered to add our design requirements into their new PDA reference design platform. Once the PDA reference design was complete, the IC manufacture would provide the six units for the petrochemical study. Although this was an excellent low cost approach in meeting the processing system design requirements, the PDA reference platform design experienced unforeseen development delays.

As it turns out, we have not fielded our PDA processing system due to lack of hardware availability and an operating system with a Java compliant web browser. In order to complete our project in the time allotted, we had to customize an existing commercial wearable computer system that, although was chosen because it was the closest to the intrinsic safety requirements and could accommodate the type of RF LAN we installed, was much bigger and bulkier than we wanted and that our customers are willing to carry around beyond our initial field test.

APPLICATION SOFTWARE

Because our second-generation system has a direct manipulation input device, we were able to design a more traditional user interface in the second year than in the first year. The application software was client-server, to take advantage of the RF network, minimize power consumption requirements for the client, and support collaborative operations across users in the refinery. Our goals in designing the application software were two-fold:

1. Make the software personalized, customizable, and collaborative.
2. Develop core software functionality that demonstrates the utility of the PIPS system.

After surveying the customer base (Reinhart, Guerlain and Whillock, 1996a), we prioritized a list of applications that we wanted to demonstrate:

- routine duties, checklists and other procedures,
- data entry log sheets,
- task schedules, and
- access to process data

The system uses a client-server architecture, with client applications being written in Java. The PIPS server accesses near real-time process data from the refinery's history module (a system that captures process data to a database in order to historize it). The PIPS server also accesses a relational database that stores the refinery's procedures, task schedules, and personnel information. We designed the relational database to suit our needs, as much of this information is currently paper-based, or scattered throughout various information systems in a refinery. Our relational database also stores sign-offs of procedures, data entry logs taken in the field, and provides a mapping between procedures and process data, so that live process data can be displayed in the middle of procedure steps when relevant. The database also stores an individual user's "favorite" process points and groups of process points, so that operators using the system can personalize and customize the environment to suit their needs. This is so users of the system can have some "ownership" of the system, since the hardware itself is shared by operators (it is intended that there are enough devices to cover all the positions worked by a shift team, but as people change shifts, they pass the device on to the next person).

We also developed database maintenance and configuration tools, to allow customers to customize the relational database to their site. We have a tool for editing employees, including a record of qualified job skills for each employee so that we can match employee skill levels to the skill requirements of various procedures. We also have a tool for entering procedures. Each procedure can have a set of steps associated with it. Each step in a procedure is assigned to one or more job skills. One can also configure process data to be displayed as part of the step, or link a data entry control (such as an on-screen keypad) for capturing an outside reading taken from the field. (For purposes of the field test, these last two options are fairly specific to a certain type of display, rather than allowing the person configuring the system to have extensive control over how this is done). Finally, there is the ability for administrators of the system to schedule procedures to be done either on a unique, one-time basis or periodically (either every shift, daily, weekly, monthly, or annually), either using the database maintenance and configuration tools, or using the client web-based software.

The client software as used by a field operator has an opening screen for logging on to the system. Employees at the refinery are grouped into four groups (A, B, C, or D), so, to log on, a user selects his/her group, name, and current job skill from his/her list of qualified job skills (many operators are qualified for more than one job skill), and enter a numeric password via an on-screen keypad. (Since we have no keyboard with our hardware design, all data entry is currently done using on-screen controls.)

Once logged on, users can navigate to different applications using the taskbar located at the bottom of the screen. The "View Today's Tasks" option (see Figure 6) displays all scheduled tasks assigned to the employee's logged on position for the current shift. In our test system, we entered and scheduled all routine daily, weekly, monthly, and annual tasks for the test site (about 400 procedures in total). The user can select each procedure from the list of assigned tasks at the top of the screen, and the procedure is displayed at the bottom of the screen. Only those procedures that contain steps for the currently logged in employee are displayed by default. This limits the number of procedures displayed for any given person (although the employee can choose to show all tasks or only those tasks assigned to another job skill if so desired). Some procedures require multiple people to perform them. Those steps that are assigned to the currently logged in operator have a white, active checkbox next to them. The operator clicks on the checkbox when he has completed that task, and the system logs his name and the date and time in the relational database. The screen updates by filling in the checkbox and displaying the operator's initials. Those steps that are assigned to other employees are grayed out (inaccessible) to the currently logged in operator, but each operator can see the status of the other employee's tasks (the system updates sign-offs in real time). When all steps in a procedure have been completed, the procedure is marked as "Done" by placing an "X" in the Done column for that procedure. This gives a high-level status overview for those wanting to see progress of the field operations.

Insert Figure 6 here

One benefit to on-line, interactive procedures is that we can make the procedures more context-sensitive. In Figure 7, we show an example of how we do this, by displaying live process data right inside a procedure step, and allowing outside operators to enter outside readings directly from the field. This procedure originally required operators to call in tower level readings (over the radio) to the central control room operator, to ensure that the control system's readings of those levels were calibrated with the manual readings displayed in the field. With our system, outside operators can now see the live process data, precluding the need to bother the central control room operator for this information. If the outside reading is significantly out of range, the user can call up an on-screen data entry keypad (using the ">>" button) to record the outside level reading (see Figure 8). Eventually, our system could automatically generate a work order, to repair the level indicator (although in our test system we did not make this link).

Insert Figures 7 and 8 here

The "View Today's Tasks" option only shows tasks scheduled for the current day and shift. The user can select "Schedule Tasks" (see Figure 9) to navigate to different days and shifts to see what is scheduled (tasks in the past have presumably been completed, so users can see the initials associated with past tasks, but can no longer change the signoffs; tasks in the future can not be signed off either). If logged on as an administrator (all supervisors have administrative privileges), one can also schedule existing procedures, or schedule "simple tasks", one-time only requests of field operators (such as taking a particular sample reading or checking a faulty valve) (see Figure 10).

Insert Figures 9 and 10 here

The "Review All Tasks" option allows operators to review any procedure entered into the system, not just those that have been scheduled. The user interface is similar to the "View Today's Tasks" option, except that one can not sign off a procedure that has not been scheduled.

The "View Process Data" option (see Figure 11) allows the user to select and view any process data point in the refinery (information that can only currently be seen in the central control room or in the shed outside on the unit). A drop-down listbox allows the user to select the process point's alphanumeric prefix, (such as F for Flow, L for level, etc.) and then use an on-screen keypad to enter the process point's numeric identifier. Up to sixteen process points can be displayed at a time. To preclude the need to enter process point identifiers each time one logs on, users have the ability to save individual points into a "Favorites" list, or to save groups of points into a "Favorite Groups" list. These favorites are specific to each user of the system.

Insert Figure 11 here

Finally, the system has navigation buttons similar to most browsers (Back, Forward and Reload) as well as a context-sensitive help system (the system displays help relative to the current screen being displayed when the Help button is pressed). The reason we implemented our own navigation buttons, is we wanted to maximize screen space, and therefore removed from view the browser's default navigation bars and incorporated the features we needed into our own taskbar.

SYSTEM INTEGRATION

The PIPS project is nearly complete. The RF network and server have been installed and tested on site, the system software has been installed and tested on site, and we have packaged together one complete Eyewand/Wearable PC/Software system. The other hardware packages are nearly complete. Although we have not yet conducted our planned, month-long field test, we have conducted early tests of the system. Some of the results of those tests follow.

The digital wireless LAN has been verified to be fully operational. Greater than 95% percent coverage was attained. Effective data rates seen by the user vary as the communication path back to the main access point may be direct or through a repeater. In a few locations, packet errors due to signal attenuation cause re-transmittal of the information and contribute to reductions in effective data rates. Although the LAN has not been tested with application software, it is anticipated that the reduction in data rates will not impact the users' perception of performance. The data rates exceed that of a standard wired modem and therefore will appear as an improvement. Seamless roaming was monitored and verified as the connection between the mobile worker and the access point switched as the mobile device moved around the facility.

Many of the operators at the test site were trained on the use of the software when the software was installed on site. Although not conclusive, no major design flaws in the software were uncovered, and the software team made some minor modifications to the software based on operator feedback (such as providing the ability to mark a procedure step as “Not applicable”, such as when a routine procedure can not be completed due to maintenance). To accommodate this, we added an “N/A” button to each procedure step in the client software (see Figures 6 and 7). This is an example of how using a hardware system with only a mouse-based user input device places added burden on the client software to ensure that there are on-screen controls for whatever action that might need to be taken. (The software team did consider speech recognition as a supplemental input device to the system, but in the high-noise environment of a refinery, we determined this would not be a viable option.)

Early tests of the integrated hardware/software system show that, as expected, the force-joystick mouse on the Eyewand is somewhat challenging to use. Some people can accommodate its use right away, while others have a rather difficult time controlling the pointing device. One interesting phenomenon is that about half the population perceive the up/down motion of the pointing device to be counterintuitive. The left /right mapping makes sense to everyone using the device, but, psychophysically, some people feel that pushing the mouse towards the top of the Eyewand (towards themselves), should make the cursor go down, whereas for others it feels “right” for the cursor to go up when pushing the cursor towards themselves (which is the way the mouse is designed by the manufacturer). This difference in perception by the population suggests that the up/down mapping of the cursor should be configurable by the end user, while keeping the left/right mapping intact, but this is not an option available with this device (since it was designed for laptop types of devices, not for devices held to the eye). Device training and familiarity of use are expected within 4-8 hours of use.

LESSONS LEARNED

One lesson that we have learned is that the paradigm shift towards wearable computers is challenging due to the required change in existing software applications. Although we tried to design our system as open as possible, with a distributed architecture that allowed our PIPS server to access existing as well as new databases, we still find those who request the ability to run existing desktop applications, as is, out in the field. Our argument is that the desktop environment was designed for just that, the desktop, and is not the right paradigm to follow when designing for field operations.

Another lesson was the codependence of software/hardware design. In our case, determining software design requirements was a challenge when both wearable hardware and RF design decisions had the potential to largely impact the type of software that should be (or could be) developed. Early on, we had to trade off whether the mouse should be one button or two, and decided to abandon the second mouse button in order to make the Eyewand shorter, and therefore easier to grip and stabilize with one hand. The NetPC team’s efforts to select the operating system, web browser software, and Java Virtual Machine delayed the selection of the development platform. We were designing a cutting edge system, and depending on other design teams, some of whom were outside of our control, to deliver systems to us. Consequently, we did not have a solid platform definition and this made software development more difficult.

Finally, it is worthwhile to note that in the two years that we have been working on this project, the interest in our customer base has been strong and continues to grow. There have been and continue to be many attempts at providing a viable solution for the roving refinery operator, although no existing system has yet proven itself viable enough to be widely adopted in this industry. We feel that a user-centered approach like the one followed here provides the best chance for packaging these technologies into a usable, successful system.

ACKNOWLEDGMENTS

We would like to acknowledge and thank the NIST Abnormal Situation Management Consortium, which partially funded this project. In particular, we thank those people at the AMOCO Whiting Refinery, most notably Chuck Mikels, George Dzyacky, Joe Stahura, Mike Clark, and all the field operators, who have supported this project by providing us with a test site, feedback on our designs and subjects to test the system.

We gratefully acknowledge Dan Cunegin and Brett Johnson of Logica who helped with the industrial design, CAD, and plastic molding of the wearable hardware, casings, and holstering devices.

Finally, this work would not have been possible without the technical expertise of Honeywell employees working on this project - Program Management and Principal Investigator: Scott Nelson; Software User Interface: Stephanie Guerlain; Software Architecture and Implementation: Dave Spoor, Ron Blair, Olu Olofinboba, and Bob Haschart; RF Network Design and Implementation: Tom Romanko, Jerry Drexler, Jerry Kooyman, Bob Wentink, and Ernie Tilley; Hardware Design and Ergonomics: Jim Lee, Bill Reinhart, Steve Metz, Rand Whillock, and Bob Demers; Optics Design: Justin Droessler; Electronics Engineering and Circuit Board Design and Implementation: Mike Helgeson, Troy Kopischke, Peter Reutiman, Brian Schmalz, and John Fischer.

REFERENCES

Reinhart, W., Guerlain, S., and Whillock, R. (1996a). *User Interface for Personal Information Processing Systems: Interim Status Report*, Honeywell Technology Center Technical Report.

Reinhart, W., Guerlain, S., and Whillock, R. (1996b). *User Interface for Personal Information Processing Systems: Phase 1 Final Report*, Honeywell Technology Center Technical Report.

Smailagic, A. and Siewiorek, D. (1996). *Matching interface design with user tasks. Modalities of interaction with CMU wearable computers.* IEEE Personal Communications, 3(1), IEEE Communications Society, pp. 14-25.

LIST OF TABLES

Table 1

Field-of-View	25 degree H x 20 degree V 30 degree diagonal
Resolution	800 x 600 24μm pixels
Nyquist Acuity	~20/37 for the AMLCD
Minimum Eye Relief	32 mm
Diopter Adjustment	None

Table 2

Operating System - Hardware Architecture	Support Java 1.1 Web Browser, 800 x 600 PEL resolution for FPD, Mouse support
Processing Performance	OS Java VM Java Compliant Web Browser
Flash	OS Storage Java VM Storage Java Compliant Web Browser Storage
RAM	32 Mbytes RAM for web page storage
Peripheral	Standard mouse RS232 interface Serial, parallel, or PC card interface for RF LAN
Display Drive Circuitry	Monochrome 16 gray scale SVGA 800x600 resolution @ 60 frames/sec
Weight	Same as radio, ~1.5 lbs
Size	Same as radio, ~1.5 lbs
Battery Life	8 hours continuous use Rechargeable battery implementation
Operating Temperature	-40 to +70 degrees Celsius
Certifications	Class 1, Div 2 - UL1604 for petrochemical environment

LIST OF FIGURES

Figure 1

Figure 2

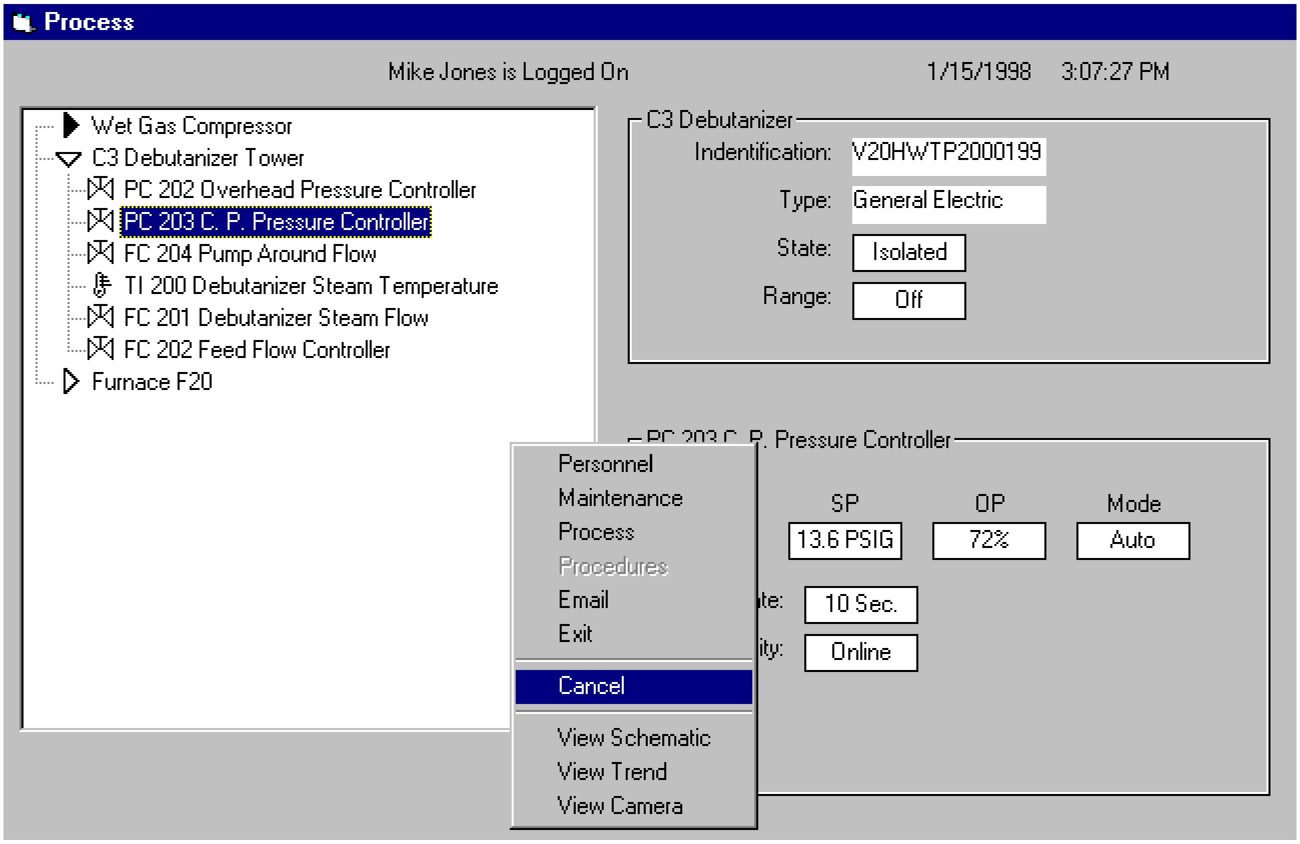
Process
Mike Jones is Logged On
1/15/1998
3:07:27 PM
Wet Gas Compressor
C3 Debutanizer Tower
PC 202 Overhead Pressure Controller
PC 203 C. P. Pressure Controller
FC 204 Pump Around Flow
TI 200 Debutanizer Steam Temperature
FC 201 Debutanizer Steam Flow
FC 202 Feed Flow Controller
Furnace F20
C3 Debutanizer
Indentification:
V20HWTP2000199
Type:
General Electric
State:
Isolated
Range:
Off
PC 203 C. P. Pressure Controller
SP
OP
Mode
13.6 PSIG
72%
Auto
10 Sec.
Online
Personnel
Maintenance
Process
Procedures
Email
Exit
Cancel
View Schematic
View Trend
View Camera

Figure 3

Figure 4

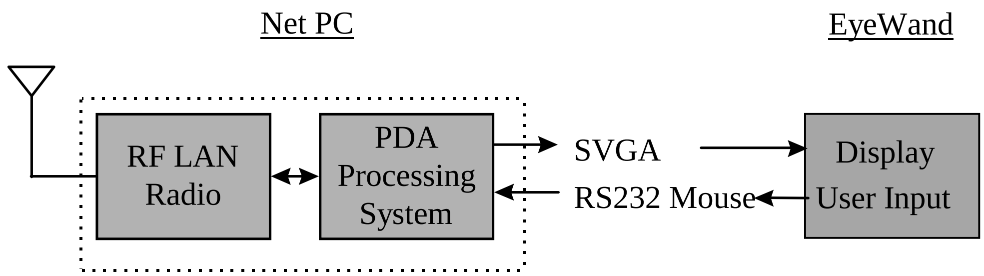
Net PC
EyeWand
RF LAN Radio
PDA Processing System
SVGA
RS232 Mouse
Display
User Input

Figure 5

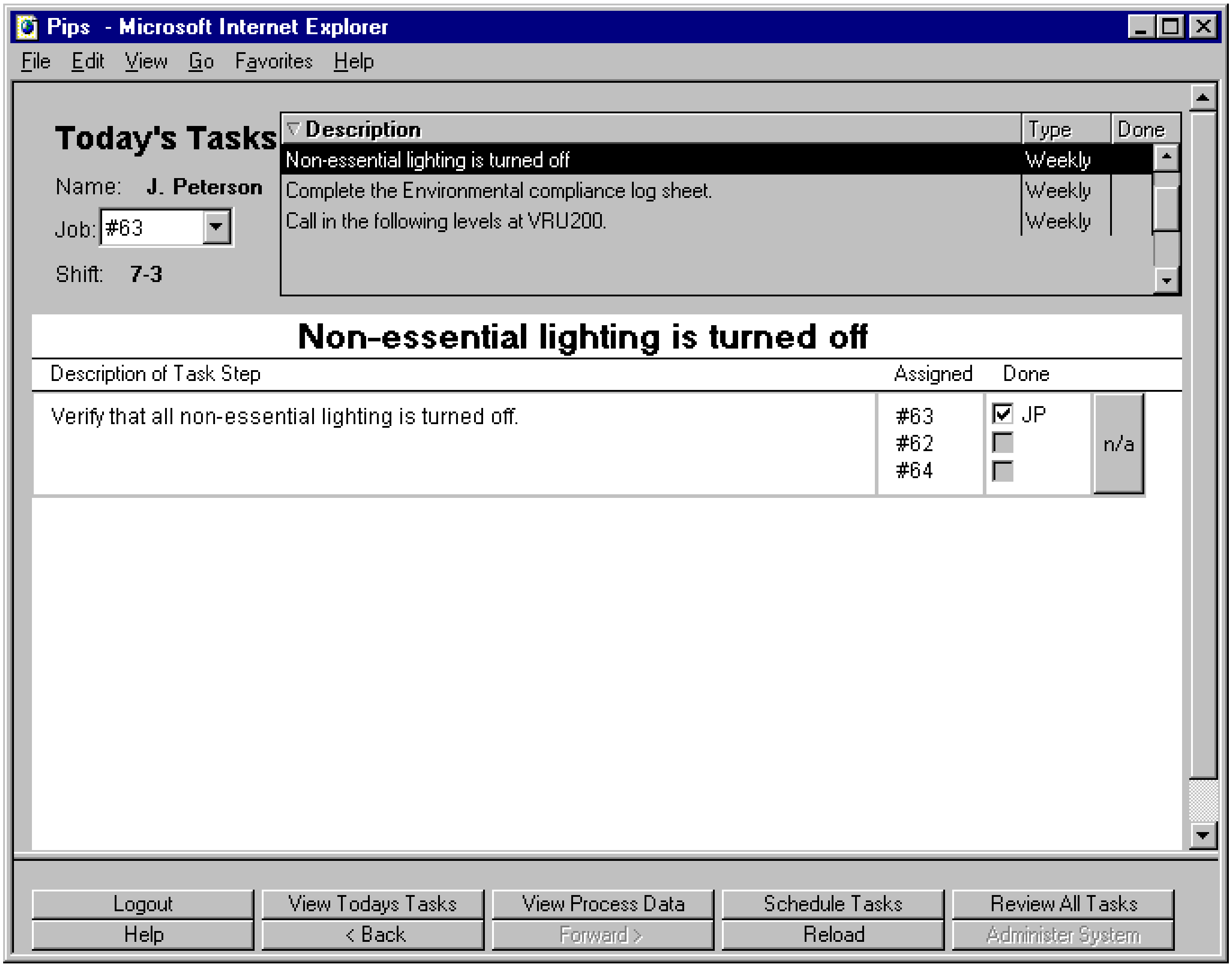
Pips - Microsoft Internet Explorer
File Edit View Go Favorites Help
Today's Tasks
Name: J. Peterson
Job: #63
Shift: 7-3
Description
Type
Done
Non-essential lighting is turned off
Weekly
Complete the Environmental compliance log sheet.
Weekly
Call in the following levels at VRU200.
Weekly
Non-essential lighting is turned off
Description of Task Step
Assigned
Done
Verify that all non-essential lighting is turned off.
#63
#62
#64
JP
n/a
Logout
View Todays Tasks
View Process Data
Schedule Tasks
Review All Tasks
Help
< Back
Forward >
Reload
Administer System

Figure 6

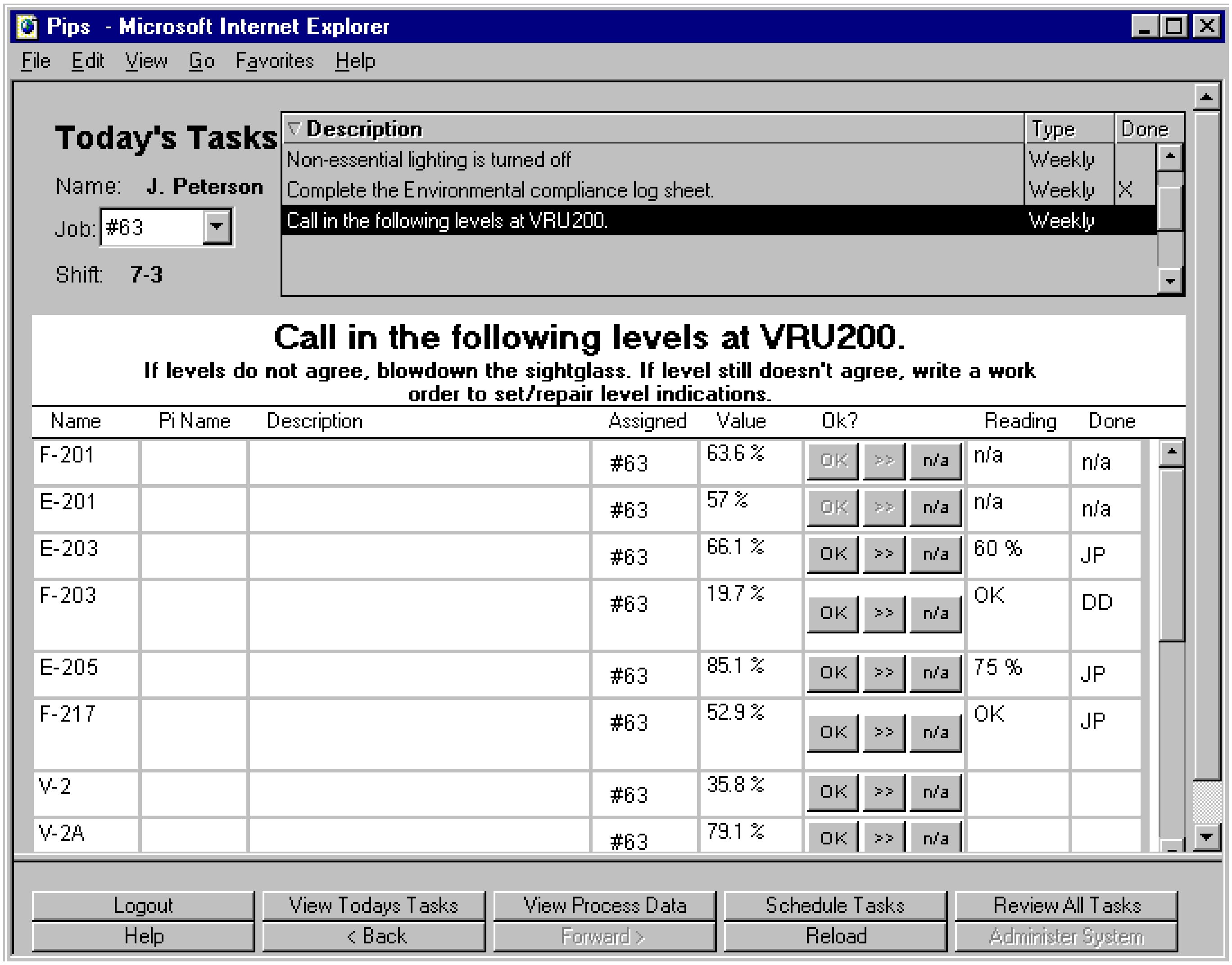
Pips - Microsoft Internet Explorer
File Edit View Go Favorites Help
Today's Tasks
Name: J. Peterson
Job: #63
Shift: 7-3
Description Type Done
Non-essential lighting is turned off Weekly
Complete the Environmental compliance log sheet. Weekly X
Call in the following levels at VRU200. Weekly
Call in the following levels at VRU200.
If levels do not agree, blowdown the sightglass. If level still doesn't agree, write a work order to set/repair level indications.
Name Pi Name Description Assigned Value Ok? Reading Done
F-201 #63 63.6 % OK >> n/a n/a n/a
E-201 #63 57 % OK >> n/a n/a n/a
E-203 #63 66.1 % OK >> n/a 60 % JP
F-203 #63 19.7 % OK >> n/a OK DD
E-205 #63 85.1 % OK >> n/a 75 % JP
F-217 #63 52.9 % OK >> n/a OK JP
V-2 #63 35.8 % OK >> n/a
V-2A #63 79.1 % OK >> n/a
Logout
View Todays Tasks
View Process Data
Schedule Tasks
Review All Tasks
Help
< Back
Forward >
Reload
Administer System

Figure 7

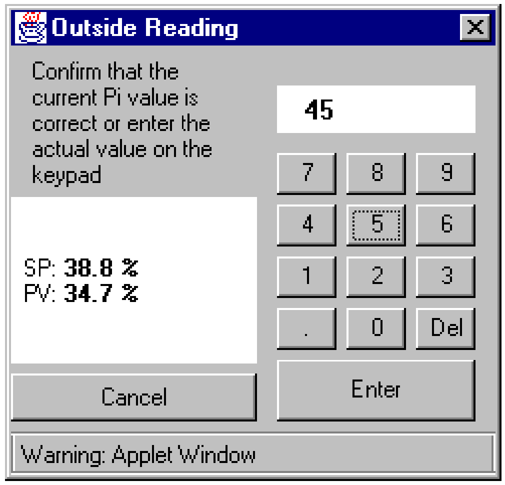
Outside Reading
Confirm that the current Pi value is correct or enter the actual value on the keypad
45
7
8
9
4
5
6
1
2
3
.
0
Del
SP: 38.8 %
PV: 34.7 %
Cancel
Enter
Warning: Applet Window

Figure 8

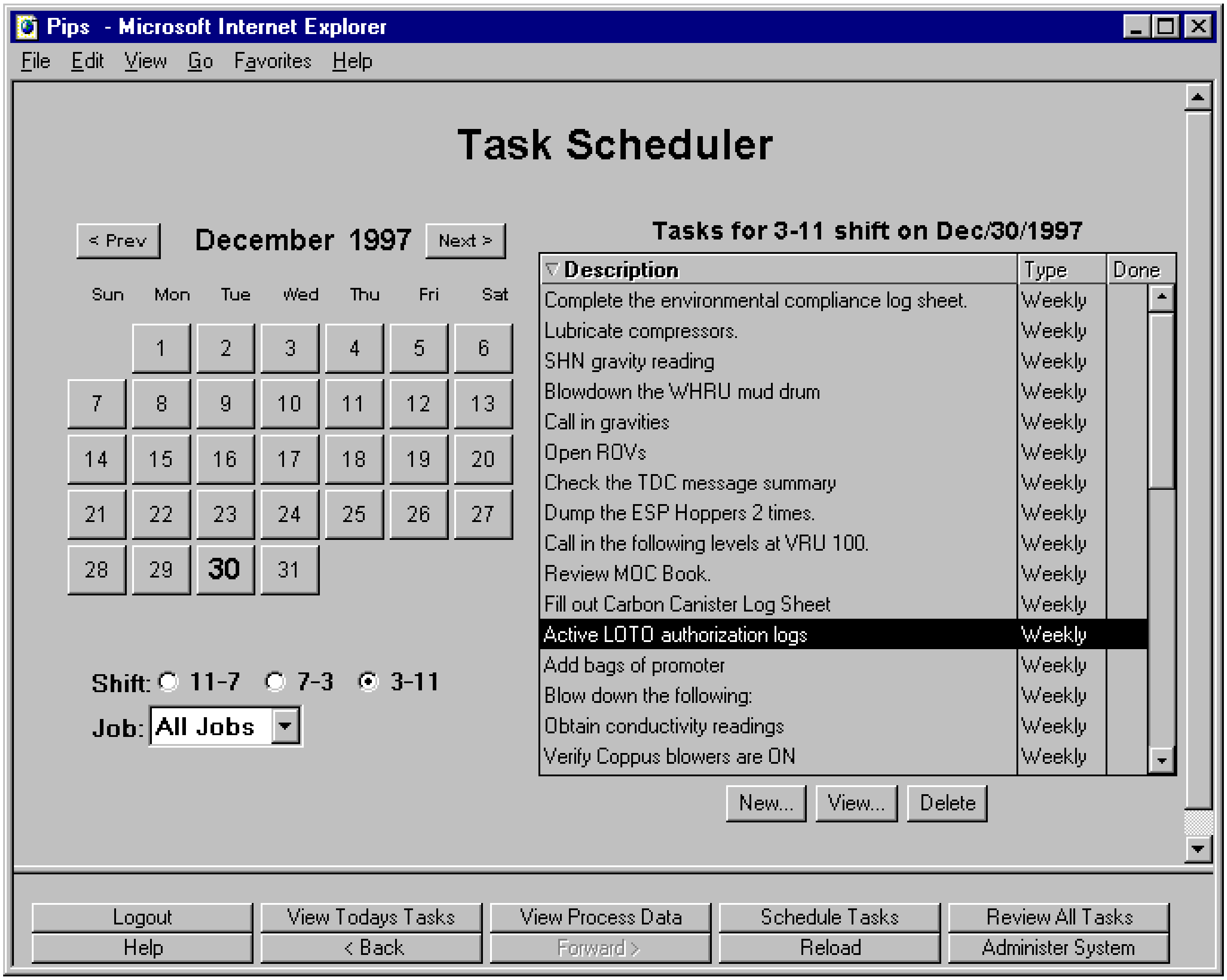
Pips - Microsoft Internet Explorer
File Edit View Go Favorites Help
Task Scheduler
< Prev
December 1997
Next >
Sun Mon Tue Wed Thu Fri Sat
1 2 3 4 5 6
7 8 9 10 11 12 13
14 15 16 17 18 19 20
21 22 23 24 25 26 27
28 29 30 31
Shift: 11-7 7-3 3-11
Job: All Jobs
Tasks for 3-11 shift on Dec/30/1997
Description
Type
Done
Complete the environmental compliance log sheet. Weekly
Lubricate compressors. Weekly
SHN gravity reading Weekly
Blowdown the WHRU mud drum Weekly
Call in gravities Weekly
Open ROVs Weekly
Check the TDC message summary Weekly
Dump the ESP Hoppers 2 times. Weekly
Call in the following levels at VRU 100. Weekly
Review MOC Book. Weekly
Fill out Carbon Canister Log Sheet Weekly
Active LOTO authorization logs Weekly
Add bags of promoter Weekly
Blow down the following: Weekly
Obtain conductivity readings Weekly
Verify Coppus blowers are ON Weekly
New...
View...
Delete
Logout
View Todays Tasks
View Process Data
Schedule Tasks
Review All Tasks
Help
< Back
Forward >
Reload
Administer System

Figure 9

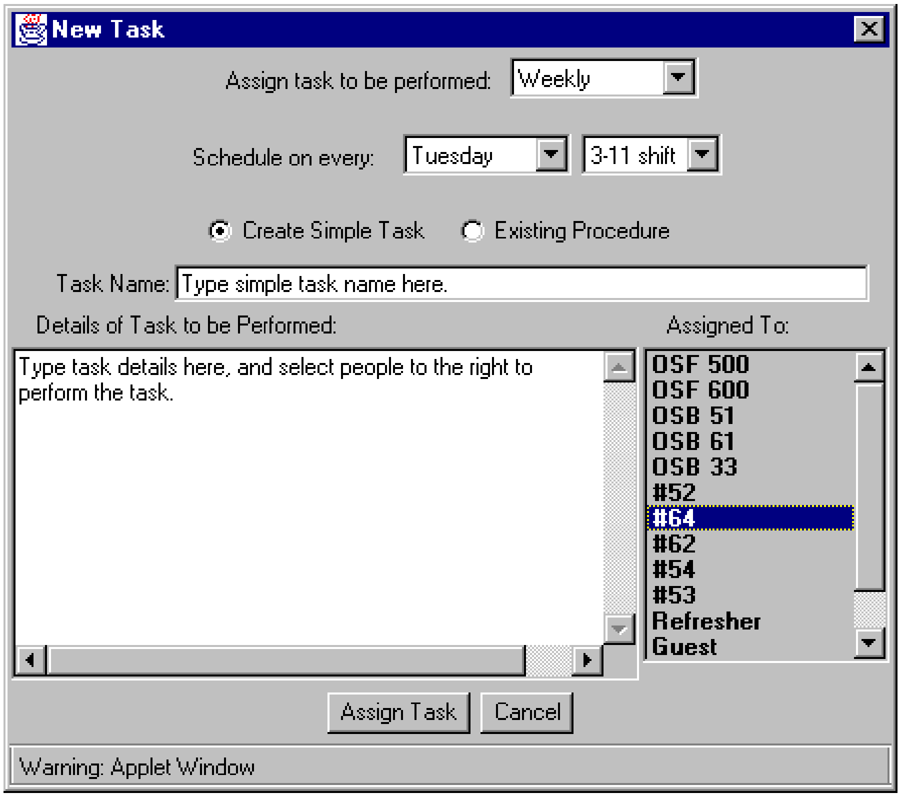
New Task
Assign task to be performed:
Weekly
Schedule on every:
Tuesday
3-11 shift
Create Simple Task
Existing Procedure
Task Name:
Type simple task name here.
Details of Task to be Performed:
Assigned To:
Type task details here, and select people to the right to perform the task.
OSF 500
OSF 600
OSB 51
OSB 61
OSB 33
#52
#64
#62
#54
#53
Refresher
Guest
Assign Task
Cancel
Warning: Applet Window

Figure 10

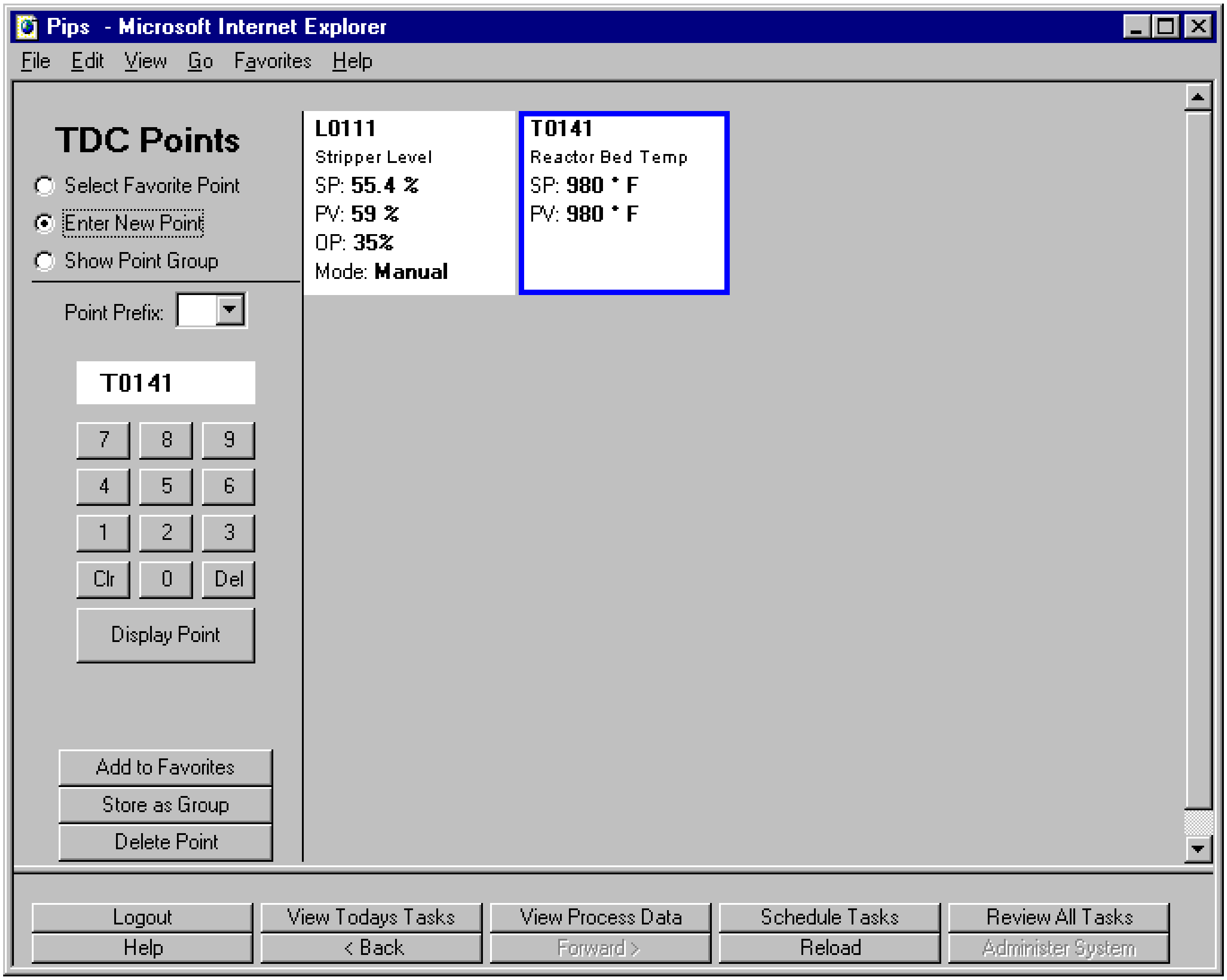
Pips - Microsoft Internet Explorer
File Edit View Go Favorites Help
TDC Points
Select Favorite Point
Enter New Point
Show Point Group
Point Prefix:
T0141
7 8 9
4 5 6
1 2 3
Clr 0 Del
Display Point
Add to Favorites
Store as Group
Delete Point
L0111
Stripper Level
SP: 55.4 %
PV: 59 %
OP: 35%
Mode: Manual
T0141
Reactor Bed Temp
SP: 980 ° F
PV: 980 ° F
Logout
Help
View Todays Tasks
< Back
View Process Data
Forward >
Schedule Tasks
Reload
Review All Tasks
Administer System

Figure 11