INCORPORATING DIGITAL PROCESSORS INTO COLLECTIVE PROTECTION SHELTER SYSTEMS – AN ARCHITECTURE, ITS SYNTHESIS, AND THE BENEFITS DERIVED

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ABSTRACT

A multiprocessor, digital control subsystem for use in the Chemically and Biologically Protected Shelter System (CBPSS) is described. This subsystem replaces hardwired, relay and diode logic now in use with a programmable logic controller (PLC). It also replaces existing pressure gauges, switches and annunciators with a membrane switch panel and graphic display combo. The use of a PLC eases the incorporation of changes in system operation, as well as changes in system design. It does so by allowing quick reprogramming of the control logic and the input/output maps. The PLC also allows installation of health monitoring sensors to diagnose current operation and prognosticate future performance. The microprocessor that controls the user interface affords flexibility in the data that is presented to the user, as well as in the presentation format. Additionally, the new design brings with it weight and cost savings.

INTRODUCTION [1, 2]

Collective protection systems are designed for use in medical and non-medical applications. These systems serve a vital role in the medical area because battlefield casualty treatment must continue even in the presence of a chemically or biologically contaminated environment. Additionally, collective protection allows individuals to eat and rest, as well as enjoy temporary relief from the individual protection equipment. Prominent examples of collective protection are the Chemically Protected Deployable Medical System (CP DEPMEDS), the Chemically Hardened Air Transportable Hospital (CHATH), the Chemically and Biologically Protected Shelter System (CBPSS), the Simplified Collective Protection Equipment (SCPE), and the Joint Transportable Collective Protection System (JTCOPS).

Of special interest to the work presented in this paper is the CBPSS. The CBPSS is meant to replace the M51 Chemically Protected Shelter. It offers a transportable, contamination free, and environmentally controlled work area for medical treatment units. It consists of an inflatable tent, and a power and support system. The latter provides heating, cooling and air filtration, as well as electrical power for lighting and equipment. The primary source of power is the engine of the HMMWV that serves as its mobility platform. A 10kW generator set mounted on a towed trailer provides auxiliary electric power. The tent provides 300ft^2 of floor space. Entry to the tent is via a litter-patient airlock, and an ambulatory patient airlock. The system also has a removable side-entrance that permits side-by-side integration with other units. A photo of a deployed CBPSS is shown in Figure 1.

Collective protection shelters, such as the CBPSS, are designed and built for the sole purpose of providing a safe haven from chemical and biological agents present in the environment. To ensure their prolonged and reliable operation it is essential to have timely maintenance built into their operation.

Figure 1. Photo of two fully deployed CBPSSs. The HMMWV serves as the mobility platform for the system. The ambulatory patient airlock, and the side-by-side connection between the two units are clearly visible.

DIAGNOSTICS AND PROGNOSTICS

There are two traditional approaches to equipment maintenance, one is preventive maintenance, and the other is corrective maintenance. In the former case, maintenance is performed at predefined intervals of time or usage. These intervals are at worst based on rules-of-thumb, and at best based on worst-case analysis of the equipment operation. In the case of corrective maintenance, equipment servicing is delayed until the equipment breaks down. This reduces life-cycle costs, and equipment availability. Clearly then, when it comes to collective protection, corrective maintenance is definitely not a practical approach. The collective protection equipment must be in good operating condition at all times. Equipment failures translate into loss of life. Hence, preventive maintenance, also called time-based maintenance (TBM), is the accepted practice. The problem with TBM is that, in general, the equipment is serviced and/or replaced way before it is actually necessary. This results in high operating costs. And, the practice does not guarantee failure-free operation. A good example of the expensive nature of TBM is the replacement of NBC filters. Standard procedure is to replace the filters a fixed number of hours after they have been installed. However, a set of NBC filters was recently removed from a U.S. warship after an exceedingly long time in service. The expectation was that the filters' remaining service life would be short, but lab analysis showed that in fact very little of the filter's capacity had actually been used [3].

An alternative maintenance approach is condition-based maintenance (CBM). This practice requires continuous monitoring of the equipment operation to determine first if the equipment is operating properly (diagnosis), and second how much longer it can remain operational before servicing or repair is needed (prognosis). A cursory review of the available literature on the subject shows that CBM is being applied to aircraft, ships, and tanks, as well as to structures [4, 5, 6, 7, 8, 9, 10].

The implementation of CBM requires the use of sensors to measure equipment and environmental parameters, the use of sophisticated mathematical models and algorithms to validate and analyze the data collected, and the use of computers to collect and process the data. The sensor suite can be comprised of the sensors already built into the system under analysis, externally attached sensors, or a combination of both. End-user observations may form part of the sensor dataset. The computer can be embedded into the system, or externally connected to it. Use of an extensible interface is essential to the system since it affords easy upgrade of the diagnostic and prognostic (D&P) analysis "subsystem" as new equipment becomes available in response to changes in the threat and/or advances in chemical and biological detection and protection technology. The digital processing architecture described in this paper represents the foundation upon which CBM can be made a reality for collective protection shelter systems in general, and the CBPSS in particular.

THE CBPSS CONTROL PANEL – THE STATE OF THE ART

The state-of-the-art in control panel design for collective protection shelters, such as the CBPSS, is based on the use of electromechanical relays and diodes as the means to implement the logic that controls the operation of the shelter. And, the connections between these relays and diodes are hardwired, point-to-point connections. To make a change in the control logic one must rewire portions of the control panel. The addition of relays or diodes can be hindered by space limitations.

The interior dimensions of the CBPSS control panel enclosure are roughly 34 inches high, 10 inches wide, and 10 inches deep. This volume is occupied, from top to bottom, by circuit breakers, power relays and switches, pressure gauges, control relays and diodes, temperature control module, and power and signal connectors.

The user interface consists of pushbutton and rotary switches, as well as, visual indicators and aural alarms used to monitor the operation of the shelter system. The pressure gauges monitor the shelter over-pressure, and the pressure drop across the NBC filter. The interface is arranged as follows, from top to bottom, circuit breakers, pressure gauges, ECU mode switches, temperature control, aural alarms, visual indicators, and control switches.

Figure 2 shows photographs of the exterior and interior of the CBPSS control panel assembly. The wire bundles visible on the control panel door evidence the complexity of the internal wiring. The total weight of the assembly is 75 pounds.

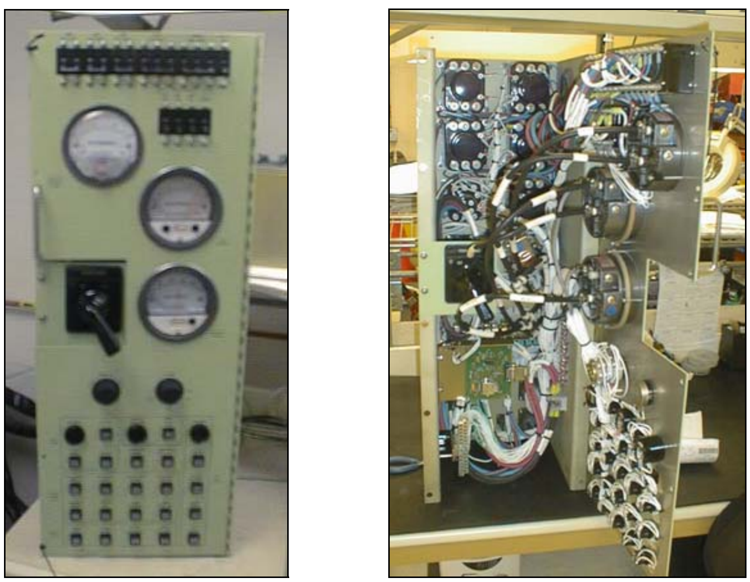

Figure 2. Photos showing the exterior (left) and the interior (right) of the control panel assembly.

Can the current CBPSS design support a CBM approach to maintenance? The answer is no. The use of relay logic prevents the implementation of a CBM approach, because it does not provide the programming and data processing capability necessary to implement D&P math models and algorithms. Then, there is no alphanumeric or graphical interface through which to convey the results of a D&P analysis to the user. Finally, the sensors in the CBPSS are discrete in nature, e.g. pressure and temperature switches, so data collection for trend analysis is impossible. If CBM is to become a reality for the CBPSS, then a revolutionary design change in the control panel assembly is required.

THE DIGITAL CONTROL PANEL

The driving force behind the control panel redesign described in this paper has been the incorporation of a CBM approach into the operation of the CBPSS. The main objective of the effort has been to put together a modular, re-configurable, and programmable control panel assembly that is "plug-and-play" compatible with the current CBPSS, and capable of supporting the implementation of D&P models and algorithms. The new design replaces the current hard-wired, electromechanical relay and diode logic with a programmable and an extensible architecture based on the use of digital processors. It also replaces the pneumatic pressure gauges, pushbutton switches and indicators that serve as the user interface in the current design with an integrated switch panel and graphic display. This radical redesign approach leads to four operational benefits.

First, the use of a programmable digital processing architecture makes the incorporation of changes in shelter operation, and shelter components, as simple as a software change to the shelter control logic, and the input/output signal mapping. Second, it allows the installation of additional sensors, distributed throughout the system, for the purpose of diagnosing failures and prognosticating future performance. Third, it affords flexibility in the manner that operational data is presented to the end-user through the use of a graphic display. And fourth, it offers weight and cost savings over the current control panel design.

In its most general form the digital control panel architecture being synthesized contains a plurality of programmable digital processors. It interfaces with the end-user through audiovisual and tactile means. The audiovisual link displays the state of the collective protection shelter, e.g., NBC filter loading, airflow, and shelter overpressure. And, it provides feedback to actions initiated by the end-user, e.g., turning an air blower ON/OFF, adjusting the shelter temperature, and muting an alarm. The forms of audiovisual communication include text, color, graphics, and sound. The user inputs are set by the position of switches and rotary encoders. The processors are connected to the sensors and actuators present in the shelter. They collect data in analog, digital and/or discrete form from the sensors, e.g., temperature, pressure, and chemical data. Signal conditioning and transformation is done as needed to ensure that the value and units of the measured parameters are correct. Data is output in analog, digital and/or discrete form to the actuators in the shelter. The electrical power available in the shelter system is used to generate the voltages and currents required by the sensors and actuators. The control panel architecture also controls the availability of electrical power to other shelter components.

The "CBPSS" embodiment of the digital processing architecture, illustrated in Figure 3, contains two programmable digital processors. Processor A, a PLC, manages the operation of the shelter. It collects process data, e.g. temperature, pressure and level, and operates actuators, e.g. pumps, blowers and heaters, to achieve the desired system's state. Processor B, a microprocessor, manages the user interface. It displays the system's state, senses the end-user inputs, and performs D&P computations. The two processors exchange data through a RS-232, serial communications link. A set of predefined messages is used to exchange system-state and user-action data. Electric power for operating the control panel comes from the vehicle or the external generator set. The user controls the distribution of electric power to other CBPSS subsystems through the control panel.

The enclosure that houses the digital control panel is exactly the same as that used with the current CBPSS control panel. The connectors on the back were left undisturbed to ensure a "plug-and-play" functionality. However, most of the other existing components were either relocated or eliminated. Figure 4 shows a photograph of the exterior and interior of the enclosure. The low voltage, low current electrical components are located in the top half of the enclosure. The high voltage, high current equipment is in the lower half. From top to bottom we have the PLC, the mode control switches, the solid-state relays (SSR), and the power and signal connectors. Comparing Figures 2 and 4 we see that the wiring inside the unit has been significantly reduced by the use of the PLC and the membrane switch panel. The new arrangement helps reduce internal electromagnetic interference, and lowers the center of gravity of the control panel assembly.

A significant weight reduction was achieved by using SSRs in place of electromechanical power relays. The six power relays in the current design weigh a total of 18 pounds. In the digital design there are nine SSRs weighing a total of 3 pounds. That represents a 15 pound reduction in weight. The SSRs are mounted on two easily removable “trays”. The airflow created by the CBPSS equipment located directly below the control panel assembly is used to dissipate the heat generated by each SSR, which ranges from 11W to 28W. Each relay is mounted on a heat sink with a case-to-ambient thermal resistance between 2.2°C/W and 2.7°C/W, depending on the relay load, in an ambient temperature of 40°C. The components within the enclosure were arranged in a manner that leaves sufficient space between them to ensure the free flow of air.

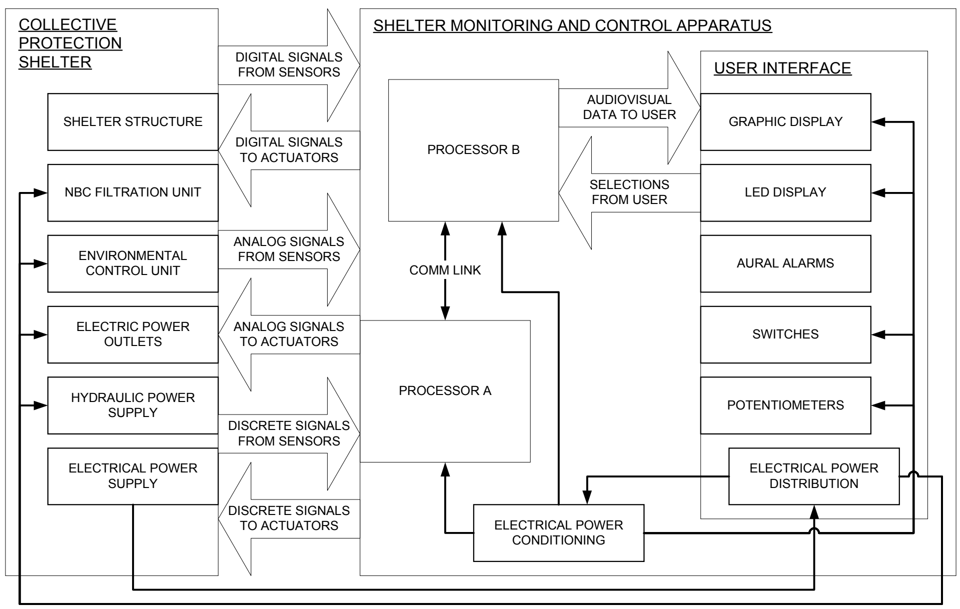

Figure 3. Block diagram of the digital control panel architecture synthesis. Processor A manages the interface to the shelter, while Processor B manages the interface to the end-user. The two processors exchange data via a communication link.

The PLC comprises three modules, including the processor module. There are two discrete input/output modules that provide a total of 32 discrete inputs, and 32 discrete outputs. The discrete signal levels are 0VDC and 24VDC. The third module is an analog input module that provides 16 single-ended analog signal inputs. It accepts ±5V, ±10V, and 4-20 mA signals. The processor operates at 50 MHz, and provides 1 Mb of memory. It is programmed using an integrated development environment that complies with the IEC 1131 standard. This standard provides several programming paradigms in addition to the traditional Ladder Diagram paradigm used with PLCs. Three of these paradigms were used for the digital control panel. They are the Ladder Diagram (LD), the Function Block Diagram (FBD), and the Structure Text (ST). Examples of the code are shown in Figure 5. The LD paradigm offered a natural way to implement the existing relay control logic. The FBD was used to implement the data exchange with the user interface, and the analog data collection. The ST was used to implement look-up tables (LUT) associated with the data acquisition. Several libraries support the use of these programming paradigms. The more traditional library contains, amongst other things, timers, counters, and logical operators. The other libraries offer support for process control, communications, and fuzzy logic. The latter is of particular interest since it is one of the mathematical methodologies being applied to CBM.

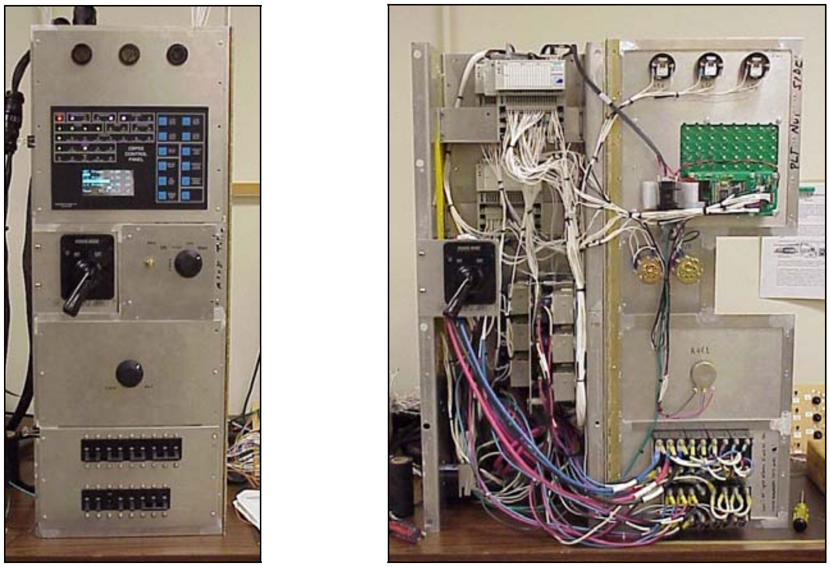

Figure 4. Exterior and interior views of the digital control panel. Visible are the aural alarms, the graphical display, the manual controls, the circuit breakers, the PLC, and the SSRs.

The new user interface “look” includes a membrane switch panel containing LED indicators and a graphic display. Figure 6 shows a photo of the interface. The LEDs show, in an abbreviated fashion, the state of the CBPSS. The user can quickly ascertain the mode of operation of the CBPSS, as well as, the status of the shelter heaters, the refrigeration subsystem, the hydraulic subsystem, the engine, and the NBC subsystem. The graphic display shows the shelter, rib, and filter pressures as bar graphs, and in numeric form. This format gives the user a visual “measure” of the current pressure value relative to the maximum possible value, as well as the actual pressure value. The acquisition and display of this data is controlled by the microprocessor, which operates at 18 MHz, and provides 512 kB of memory.

In addition to the membrane switch panel, the user interface also incorporates three rotary switches that control the operational mode of the shelter, a potentiometer that establishes the shelter temperature setpoint, three audible alarms to alert the user, and a bank of electrical circuit breakers that control AC and DC power distribution within the CBPSS.

The operation of the digital control panel was tested in a two-step fashion. A very simple hardware simulation of the CBPSS, using switches and LEDs, was used early on to test the control logic software. Then the simulator regularly used to do the final production testing of the CBPSS control panel assemblies was used to test the “plug-and-play” operation of the digital control panel assembly. The latter test required that a few quick changes be made in-situ to the PLC code to account for the fact that some of the pressure and temperature switches in the CBPSS are make-to-ground switches. The code was also changed to account for the fact that some switches and solenoids are wired together inside the “pod”, and the vehicle control panel, and thus not directly accessible to the PLC. Their individual state is in some cases being derived from the sensed state of other switches. All indications from the testing phase are that the digital control panel provides the desired operational functionality.

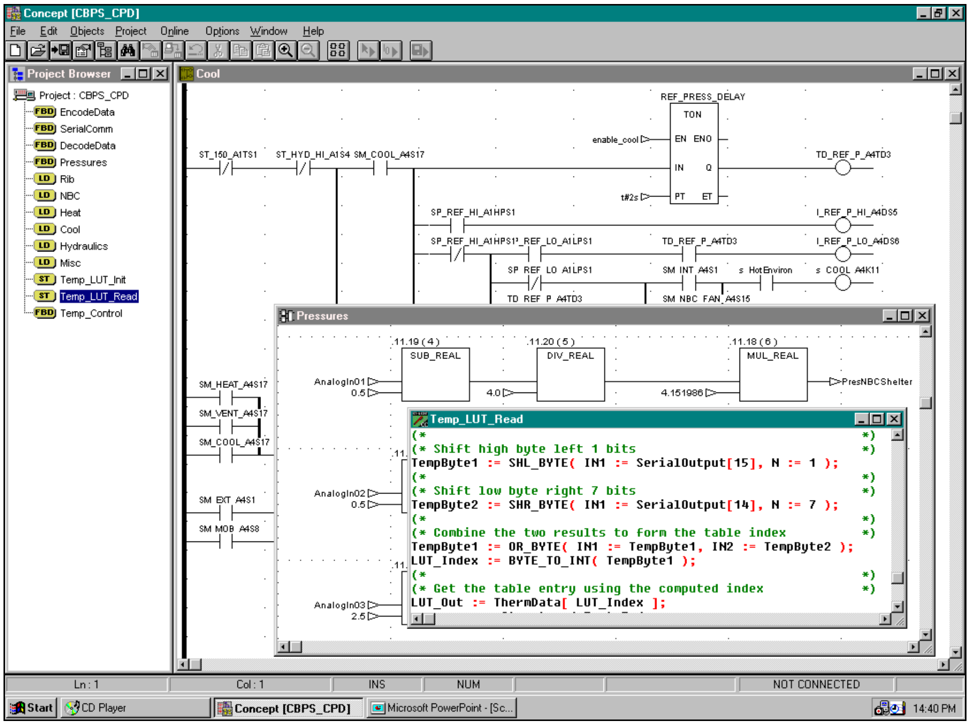

Figure 5. Screen view showing examples of the IEC 1131 programming paradigms used to program the control of the CBPSS.

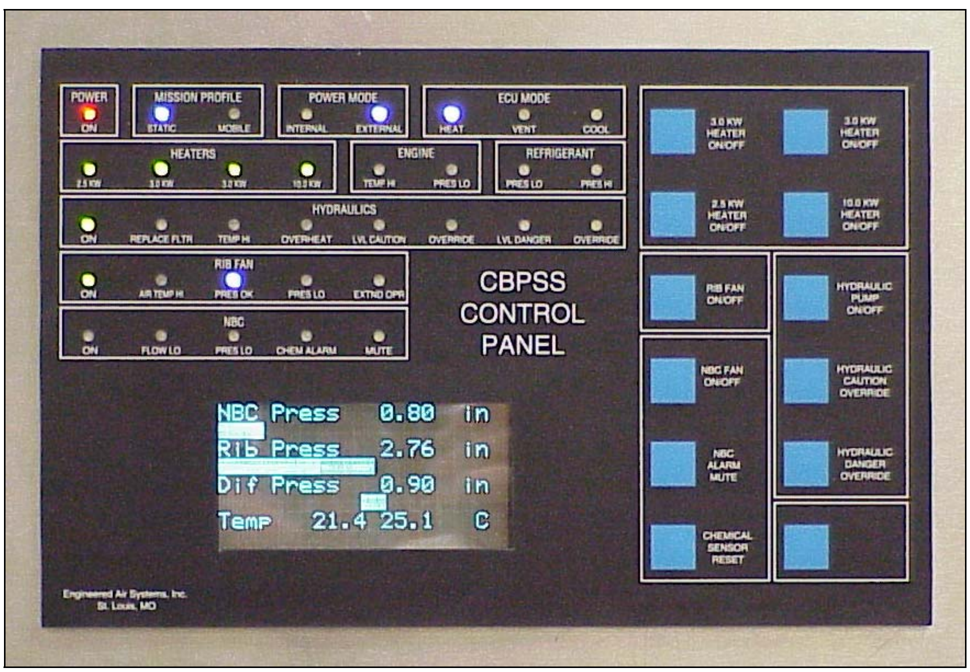

Figure 6. The membrane switch panel contains LEDs that display the status of the various CBPSS components, membrane pushbuttons to activate/deactivate heaters, fans and motors, and a graphic display of various pressure measurements.

BENEFITS OF THE DIGITAL DESIGN APPROACH

The benefits afforded by the use of a digital processing architecture described in this paper are many. And, they impact many facets of the product life cycle, i.e., production, operation, and maintenance.

In the area of production, for example, the number of connections required to interface the end-user to the control system has been significantly reduced. The use of a switch matrix topology reduced the number of "pushbutton" connections from ~63 to 7. Likewise, the use of a multiplexed LED topology reduced the number of "indicator" connections from ~181 to 13. And, there are no solder joints since the connections are made using a flat ribbon cable. Three PLC modules replaced twelve electromechanical relays. The pneumatic gauges, hoses, and connections have been eliminated from the assembly. The temperature control functionality now being provided by an electronic module has been replaced by PLC code. The bulk of the wiring inside the control panel consists of direct connections between the circular connectors on the lower back of the enclosure and the terminal blocks on the PLC modules. Fewer wiring mistakes are thus likely to occur. Because the control logic is encapsulated in software, differences in operation between shelters due to wiring errors are virtually eliminated. So, considerable savings in production labor and material costs can be readily achieved through the new approach.

In the area of operation we find that the digital control panel assembly now weighs ~50 pounds. This is 25 pounds lighter than the current production design. The weight saving means that additional medical supplies and/or equipment can be carried by the CBPSS to the field. The presence of a graphic display allows the user to view other operational data in addition to the air pressure readings. The particulars depend on the sensors installed in the shelter system. Clearly, this enhances his/her awareness of the shelter's operational state, and helps with the system maintenance.

In the area of maintenance, even without implementing a CBM approach, the self-diagnostic capability of the digital components in the control panel increases the productivity of field personnel. All the PLC modules are equipped with LEDs that allow the technician to quickly ascertain the operational status of each module, the I/O signals present, and the communication between modules. The modularity of the design simplifies making repairs to the system. In most case it simply involves a removal-insertion activity. The PLC also offers Internet connectivity, including support for web-pages, which means that D&P data could potentially be accessed using a laptop computer and a wireless communication link. One could also envision maintenance documents being electronically stored within the shelter system itself. The addition of CBM models and algorithms will considerably augment this basic level diagnostic capability.

CONCLUSIONS

The digital processing architecture described in this paper, and the synthesis presented, unarguably provides the necessary means to monitor and control the operation of a collective protection shelter. Additionally, the architecture offers the operational flexibility needed to incorporate a D&P capability into the operation of a collective protection shelter. Furthermore, the programmability of the architecture affords easy incorporation of shelter operation changes. And, its extensibility permits easy incorporation of shelter design changes. The use of electronic relays instead of electromechanical relays has been shown to result in a reduction in mechanical complexity, weight, and cost. And, the modular design of the digital control panel assembly simplifies equipment maintenance, and increases equipment availability.

Three options exist for continuing the work presented here. The more obvious one is to install the digital control panel prototype in a CBPSS, and test it as part of a fully operational CBPSS. Another option is to modify the digital control panel wiring, and PLC code, so that the prototype controls the operation of the stand-alone "pod" developed by Radian Inc., in Alexandria, VA. This "pod" is scheduled to replace the current hydraulic "pod". The third option is to begin the development of D&P math models and algorithms for the CBPSS.

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